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INTERPRETATION OF AERIAL PHOTOGRAPHS FOR GEOMORPHOLOGICAL RESEARCH

by Ye. N. Azbukina

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By Ye. N. Azbukina

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ANNOTATION

This monograph describes the application of aerial photograph interpretation in field and office geomorphological research and photo interpretation for describing relief types and forms, their origin, and interrelationships between the latter and geological structure. This manual is illustrated with aerial photographs of relief forms representative of the various landscape-geographical conditions in different regions in the Soviet Union.

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INTRODUCTION

During the last 20 years the use of aviation and aerial photographs, which are now available for a large part of the earth's surface, has become one of the principal methods employed in geological-geographical investigations. The importance of aerial photographic methods is particularly great for geomorphology, the study of the earth's relief, its origin and development. Observations from aircraft and aerial photograph interpretation make it possible to form some idea concerning the nature of the geographic landscape, morphological relief types, and the full range of recent exogenous processes. This makes it possible to judge the direction and intensity of movement of the earth's crust and the geological structure of the terrain; this is particularly important for petroleum-bearing platform regions covered by forests and regions covered by thick Quaternary deposits. Morpho-structural analysis can reduce the volume of expensive drilling work and geophysical investigations required in such cases. At the present time, geomorphological mapping based on a study of relief morphology, genesis and age is also impossible on any successful basis without the interpretation of aerial photographs.

The group of procedures which makes it possible to obtain a terrain image by photography from the air is called an aerial photographic survey. It includes aerial survey, laboratory, geodetic and photogrammetric work, which result in the production of aerial photographs, photomaps, and photomosaics. In a few hours of aircraft flight, an aerial photographic survey covers many thousands of square kilometers. These materials can be used in compiling a highly precise terrain map. The content of an aerial photograph gives the researcher more information than does a topographic map. Aerial photographic survey materials very objectively reflect the totality of components making up the natural landscape in their qualitative and quantitative interrelationship.

The term aerial methods is given to the combination of new methods for investigating nature by visual observations from the air (aero-visual observations), studying aerial photographs, maps and mosaics, and supplementing them with ground field work. In particular, they include the aerial geographical-geological survey method for studying the dependence of relief, hydrography, vegetation, soil formations, color and tonal characteristics of the earth's surface landscape on geological structure and also study of the properties of an aerial photographic survey image of the landscape and the methods for its interpretation.

So-called aerogeophysical methods have been assuming ever-increasing importance during recent years. They are based on measurements of the different physical properties of the earth from an aircraft along a stipulated system of /4
flight lines. Aeromagnetic and aerial radiometric reconnaissance are the most commonly used forms of such surveys. Aeromagnetic (airborne magnetometer) reconnaissance is for registering the field of magnetic anomalies associated with areas where particular types of rocks are found. Aerial radiometry is for measuring the gamma activity of rocks (fundamental data in the search for uranium deposits). An aerogeophysical survey is continuously accompanied by a photographic tie-in to the terrain, possibly by using a narrow-film short focal length camera of a special design. An aerial petrographic survey of rocks is highly promising.

The experience gained in aerial methodological investigations on the land has been applied to the shallow parts of the floor in seas and lakes. The investigations made by V. V. Sharkov and others have made it possible to use aerial photography for both mapping relief and deposits on the sea floor and in prospecting and exploration work for finding petroleum and gas.

Aerial methods have occupied an important place in practical geological-geographical investigations during the last two decades. Not a single major expedition in the USSR has been able to operate without aerial photography. The use of aerial methods makes possible a considerable increase in productivity and an improvement in the quality of geological-geographical studies both due to a reduction in the extent and duration of field work and through an increase in the accuracy of report materials. With each passing year the techniques for applying aerial methods are being improved and they are being successfully used in all branches of the geological-geographical sciences.

Exceptionally small-scale aerial photographic surveys (1:200,000-1:750,000 and smaller), possible when taking photographs from great altitudes, make it possible to study planetary structural patterns of distribution of the largest relief forms on the earth's surface, not shown on aerial photographs at ordinary scales. Lunar photographs are being used in compiling maps of surface relief on the moon and the rocks forming it. In the not distant future, interpretation of photographs of the Martian surface and other planets will yield valuable information concerning their relief, volcanism, rocks, and other characteristics which are of the greatest importance if man is to conquer space.

The largest establishment in the Soviet Union operating on the basis of use of aerial methods is the All-Union Aerogeological Trust [VAGT]. It is engaged in geological and geomorphological mapping and mineral exploration. The Aerial Methods Laboratory of the Geology Ministry [LAEM] is engaged in the development and improvement of aerial methods in geological-geographical investigations. A Commission on Aerial Photographic Surveying is part of the USSR State Geographical Society. Aerial methods laboratories exist at Moscow and Leningrad State Universities.

On the basis of geological-geographical studies made using aerial methods, a number of review studies have been published in the USSR during the postwar years: V. P. Miroshnichenko, Aerogeos"yemka [Aerial Geographical-Geological Surveying], 1946; M. N. Petrusevich, Aerometody pri Geologicheskikh Issledovaniyakh [Aerial Methods in Geological Investigations], 1962, Aerometody pri Geologicheskoy S"yemke i Poiskakh Poleznykh Iskopayemykh [Aerial Methods in Geological Surveying and Mineral Exploration], Volumes I and II edited by G. F. Lungersgauzen, 1965, 1966, and others. The Trudy Laboratorii Aerometodov [Transactions of the Aerial Methods Laboratory] are regularly published. All geological-geographical periodicals regularly carry articles concerning the use of aerial methods.

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INTERPRETATION OF AERIAL PHOTOGRAPHS FOR GEOMORPHOLOGICAL RESEARCH

Ye. N. Azbukina

AEROVISUAL OBSERVATIONS

The use of aviation in general geological-geographical and geomorphological investigations initially developed from direct visual observations from the air (aerovisual observations). Aerovisual observations include descriptions, sketching, visual surveying, and simple photographing of the earth's surface from an aircraft (Figure 1). These observations are a highly productive, relatively simple and effective method which has little dependence on optical atmospheric conditions and which does not require special equipment and personnel. The possibilities of the aerovisual method can be broadened by field landings of the aircraft at places without airports near the features being investigated (relief forms, geological cross sections, etc.). This method is of particularly great importance for work of an expeditionary or reconnaissance nature in thinly populated and inaccessible regions. /5*

At the present time, there are no aircraft in the USSR specially designed for aerovisual observations. A monoplane with wings situated above the fuselage, thereby not hindering terrain scanning, is convenient for this purpose. In southern regions, it is common to employ a PO-2 aircraft (a biplane), an inexpensive maneuverable craft with a low (not more than 170 km/hour) cruising speed (the speed with minimum fuel consumption). YaK-12, PO-2S, P-5, LI-2, AN-2, and AN-14 aircraft and MI-1, MI-4, and KA-18 helicopters have also been used.

Calm, clear weather, and for most regions the morning (between 0500 and 0900 hours) or afternoon hours, are suitable for making aerovisual observations. During these hours the air is characterized by maximum transparency, the aircraft is less subject to bumping, and oblique illumination emphasizes all relief details. The coloring of natural features is most clearly expressed under these conditions, a factor of great importance in their identification. It is desirable that the sun be behind the observer; visibility deteriorates when observations are made toward the sun. Observations must be made almost perpendicularly

* Numbers in the margin indicate pagination in the foreign text.

to the earth's surface so that features will be seen on a plane, not obliquely.

The direction of the observation flight lines can be parallel or in a loop (at distances ensuring complete coverage), Flight altitude is dependent on the observation objectives and relief characteristics. In lowland areas, the recommended altitude is from 100 to 500-800 m; in foothills or mountains, it is from 500 to 1,500 m or more. At an altitude of 400-500 m relief structure details are still readily distinguishable with adequately broad scanning to either side (2-3 km). By varying the flight altitude some idea can be obtained concerning the structure of local relief at different scales: from an altitude of 800-1,000 m a general scanning of the distribution of the largest relief ele- /6 ments is possible; from an altitude of about 500 m it is easy to distinguish intermediate relief forms (valleys, basins, hills, and ridges), the distribution of populated and swampy sectors, large rock exposures and quarries. The development pattern of small relief forms and their structure (river terraces, nature of slopes, swales, low hills, etc.) can be observed from an altitude of about 100 m.

It is recommended that aerovisual observations not be made for more than three or four hours per day. During this time the aircraft flies more than 400 km and exceedingly great stress is involved if during this period the observer orients himself in the air, records all visible characteristics of the geological-geomorphological structure of the terrain, photographs and sketches characteristic relief forms.

Shortcomings of the aerovisual method include lack of documentary aerial survey materials, considerable subjectivism in the observation results, and their dependence on the observer's physical condition. The presence of a tape recorder or stenographer aboard the aircraft considerably facilitates the observer's recording of observations in the air.

The aerovisual method, being simple and easy to use, is now most effective when combined with the method of interpretation of aerial photographs and field work on the ground. However, it is also used independently at times in such fields of geological-geomorphological research as geological-geomorphological mapping, search for mineral deposits, geological engineering work involved in the layout of railroads, highways, canals, dams, reservoirs, ports, etc.

I. In a geological-geomorphological survey under different landscape-geographical conditions most researchers recommend that aerovisual observations be made in three stages: preliminary reconnaissance flights; flights for refining and supplementing ground observations; final flights after ending ground investigations.

The following data can be obtained for geological-geomorphological mapping by the aerovisual method.

1. Materials for compiling maps of rock outcrops: the extent and nature of rock outcrops, their relief characteristics, approximate lithological composition of the formations covered by these materials.

2. General characteristics of surface structure, its orographic elements, definite plant associations accompanying it (forest, swamps, steppe, etc.).

3. Determination of sectors of rocks forming the region on the basis of aerovisual diagnostic criteria: color, brightness and nature of outcrops, forms of weathering, lithological stability, relationship to relief forms. For example, using the aerovisual method, it is particularly easy to identify sectors in which eolian Quaternary deposits are present.

4. Hydrogeological information on surface and ground water. This is particularly important in desert and semidesert regions where surface manifestations of ground water are readily detectable from the air, primarily from the presence of moisture-loving vegetation.

5. Geomorphological description of the region; by successively changing the flight altitude, the basic patterns of distribution of major relief forms (ridges, depressions) can be identified from great altitudes, whereas by descent to lower altitudes, it is possible to characterize intermediate (meso-) forms, and finally, from an altitude from which the microrelief elements are clearly visible some conclusions can be drawn concerning the interdependence of types and forms of macro-, meso-, and microrelief, their relationships to geological structure. /7 It is also possible to study the pattern of the erosion network, the characteristics of slope development, and the occurrence of landcreep, karst and other processes.

II. In the search for minerals, aerovisual observations are made primarily in sectors of promising areas where reconnaissance flights have revealed favorable conditions for further field work on the ground and have provided the typical criteria for identifying deposits of different types. The criteria used in searching for minerals from the air can be classified into two groups:

1. those associated with the mineralogical composition of the mineral or the country rock: color, relief form, correlation with color and composition of soils and vegetation groupings, with ancient mine workings, etc.;

2. those attributable to the overall geological structure of the region, its tectonic and lithological-stratigraphic peculiarities: presence of domed structures, correlation between ore deposits and intersections of faults, quartz veins, etc.

III. Aerovisual observations are made over great areas in support of geological engineering work in the layout of railroads and highways, canals, dams, etc. In each individual case an observation program is drawn up which must be executed for ensuring subsequent work. For example, in the alignment of railroads and highways, aerovisual observations are made for an aerial reconnaissance of the region and for interpreting inaccessible sectors; this is done both with and without landings (aerial interpretation).

In an aerial reconnaissance a region as a whole in its natural conditions can be surveyed. At an altitude of 600-900 m the landscape details are clearly visible and the nature of the relief and its dependence on the lithological composition of the rocks forming it stand out more clearly than in surface observations. An aerial reconnaissance makes possible a more precise layout of the proposed flight lines, determination of some patterns of interrelationships between relief and geological structure, detection of outcrop areas, configuration and types of swamps, valleys, etc. It is of great importance in the search for construction materials, making it possible, in relation to the key terrain landmarks, to map sandy shoals, spits, terraces with rock outcrops, and photograph them at the same time. Aerial interpretation is of secondary importance and is recommended for inaccessible and poorly studied regions (covered with extensive swamps, taiga, burnt forest) or for more precise determination of geological boundaries plotted on maps during ground field work. Aerial interpretation is done from low altitudes (50-300 m), from photo mosaics or from an assembly of aerial photographs.

Aerovisual observations are therefore multisided investigations from the air for visual determination of natural features and the dynamics of natural processes. These features (relief types, erosion network, soil and vegetation types, etc., and their relationship to geological structure) are studied in relation to all the landscape-geographical conditions in the region. There are two groups of aerovisual criteria used in identifying natural features:

a) those associated with the physical composition, color, resistance to weathering, and other properties of the features themselves;

b) those associated with the spatial position of the feature, its orientation, and relationship to the general structural conditions of the region. The distinctness with which these criteria are expressed is dependent on the landscape conditions of the place of observations (geographic zone), time of day and season, nature of illumination, etc.

The aerovisual method is employed in regions inaccessible for ground observations, but also for supplementing and refining ground investigations and data obtained from interpretation of aerial photographs. The quality of aerovisual observations is dependent on the physical condition of the observer, his experience, and broad training in physical geography. /8

AERIAL PHOTOGRAPHIC SURVEY MATERIALS AND THEIR USE IN GEOMORPHOLOGICAL RESEARCH

In carrying out geological-geographical investigations, the following are the principal aerial photographic materials used: aerial photographs (contact prints, contact printing); reproduction of preliminary photo layouts, photomosaics and photomaps. The acquisition of these materials is preceded by flight survey work. Photography from the aircraft is done by special aerial cameras which take pictures of the earth's surface automatically with a preset time interval. An aerial photographic survey can be made at an angle to a horizontal surface (oblique aerial photographic survey) or vertically downward (near-vertical aerial photographic survey). The latter is most important for obtaining aerial photographs and maps.

The aircraft covering a network of linear parallel flight lines flies over the area to be photographed, at all times adhering to the same altitude in conformity to the stipulated survey scale. The time between exposures is computed and automatically maintained in such a way that at a stipulated flight velocity and altitude the end lap of successive aerial photographs (along the flight line, which in the USSR usually has a latitudinal direction) averages 60%. In addition, aerial photographs taken on adjacent flight lines must have a side lap of 30-40%.

After the flight the photographic film is developed, positive contact prints are obtained from it, and a preliminary photo layout (uncontrolled mosaic) is prepared. In the procedure the contact prints (aerial photographs) are superposed on one another, matched along the superposed edges, and pinned on a sheet of veneer. Additional flights are made if there were gaps in the photographic survey or if there are deviations from normal end and side lap. The preliminary layout is used in preparing a photoreproduction (usually with a two- or five-fold reduction); this constitutes the first photographic image of a large area.

A more perfect photographic image of the terrain is given by a photomap which is assembled from the central parts of aerial photographs glued on a base. The number of the sheet and the mean scale of the aerial photographs, as well as the year of the aerial survey and the agency which executed the survey, are printed on the photomaps.

A photomosaic is a photographic image of the terrain compiled from rectified aerial photographs, that is, photographs which have been reduced to a common scale and corrected for tilt. This leaves distortions of the relief image, which in mountainous regions are significant; accordingly, photomosaics are not compiled for such regions.

In field geomorphological investigations, it is most common to use aerial photographs (contact prints). Depending on the type of camera they measure 18 x 18, 24 x 24, or 30 x 30 cm and are numbered in sequence in conformity to sheets of the topographic map at the survey scale. In the northeast corner on each aerial photograph the year and month of the flight and the sequence number are imprinted. Each set of photos must be accompanied by a list and an information sheet describing the conditions under which the survey was made (scale, /9
time, flight altitude, focal length of the aerial camera, weather conditions) and a photoreproduction of the preliminary photo layout. The air photos must have suitable contrast and be on semimatte paper (if the surface is glossy it is rubbed with an ink eraser so that a pencil can be used on the surface).

Aerial photograph scales of 1:60,000, 1:25,000, 1:12,000, and 1:5,000 are used most frequently. In geomorphological mapping the air photo scale must be larger than the survey scale. For example, air photos at 1:25,000 are used when the survey scales are from 1:50,000 to 1:1,000,000. Air photos are selected from flight lines; this is easy to do by using a reproduction of the preliminary photo layout. They are studied stereoscopically in pairs and interpreted.

Photomaps and photomosaics are not always available; for the most part they are used in transferring the interpretation results from the aerial photographs.

In a general sense, the term "interpretation" of aerial photographs means determination and description of the categories of surface features, types of geographic landscapes, individual features or physical phenomena from their image. L. S. Smirnov defines geographical interpretation as a method for studying the geographic (landscape) appearance of the earth as a whole, its parts, landscape components, or individual elements (1967).

Until now there is no unanimity of prints of view and terminology with respect to the theory and methodology of interpretation work; accordingly, in this brief manual we will employ the terms most frequently used in the literature without their critical analysis.

Interpretation [deshifriovaniye] is a Russian term which was first employed in military instructions issued during the First World War. This corresponds to the word interpretation used in the foreign literature .

Interpretation is used in various research fields: topography, physical geography, hydrology, geology, geomorphology, forest cruising, etc.

The objective of geomorphological interpretation is study and description, on the basis of aerial photographs, maps and mosaics, of the morphology, genesis and age of the earth's surface relief and its relationship to the geological and geographic conditions of the investigated terrain.

The interpretation is based on the fact that as a result of the photographic process every sector of the earth's surface, distinctive in its physical properties from adjacent sectors, on an aerial photograph has a unique photographic image different from that for adjacent sectors. The nature of the image is also influenced by such physical properties of natural features as their size, shape, color and reflective properties, as well as their illumination conditions at the time when the photographs are taken, the quality of the photographic materials, etc. Accordingly, interpretation includes analysis of the conditions in the natural environment, that is, the properties of the features themselves and an analysis and interpretation of the factors which exerted an effect on the nature of the photo image.

The objectivity and complex representation of natural landscape elements on aerial photographs enabled Soviet researchers during recent years to develop landscape interpretation methods, methods for using indicative landscape patterns by means of a special study and mapping of their morphology, typology /10 and dynamics, that is, the rhythm of daily, seasonal and secular changes (V. P. Miroshnichenko, S. P. Al'ter, et al.).

Interpretation is based on direct and indirect criteria.

Direct interpretation criteria. Direct interpretation criteria include size, shape, spatial position of features, shadows, image tone and photo image pattern.

Direct criteria and fundamental, initial data in interpretation work. These data present on aerial photographs can be perceived directly by the observer and measured. Interpretability, the degree and completeness of description of the interpreted feature, are dependent on their clarity and their correspondence to the external characteristics of terrain features. In many cases, direct criteria are adequate for a specific description of objects and features on the earth's surface (relief, hydrographic network, vegetation, etc.), but are inadequate for describing the components of the earth's surface itself.

Psychologists believe that we recognize objects from three constants: size, shape, and color. We will examine how these criteria are applicable to aerial photographs. Size of features: the true size is not shown because the scale is distorted and there is a reduction by tens of thousands of times. Photo scale must be taken into account when features on photographs are interpreted on the basis of size.

The numerical scale is usually determined through the ratio of the focal length of the camera (f) to flight altitude (H)

$$\frac{1}{n} = \frac{f}{H} .$$

The scale of aerial photographs can also be determined by measuring:

a) the distance between the same points on an aerial photograph and on the ground (linear scale);

b) the length of segments between the same points on an aerial photograph and on a map or plan whose scale is known.

In the interpretation process, it is necessary to take into account the minimum dimensions which show up on aerial photographs at different scales. According to data from the Aerial Methods Laboratory USSR Academy of Sciences, the minimum dimensions showing up on aerial photographs are as follows:

Aerial photograph scale	$\frac{1}{5,000}$	$\frac{1}{10,000}$	$\frac{1}{15,000}$	$\frac{1}{20,000}$	$\frac{1}{30,000}$
Minimum size, in meters	0.25	0.5	0.75	1,0	1.5

The perception of the photographic image of small features is determined by the resolving power of the human eye. At a distance of 250 mm (best vision) about 6 lines/mm can be separately distinguished. A better visibility on aerial photographs can be obtained by enlarging them two, four, or more times, depending on the graininess of the film emulsion.

The shape of features is particularly important in interpretation work. The shape of a feature is not dependent on scale and remains constant. In the case of a near-vertical image of features, the shape is unusual because we are accustomed to seeing the surface at an angle. Geometrical configuration is used in interpreting roads, cultivated fields, gardens, and settlements, which are identified from their regular geometrical contours and lines. The hydro- /11
graphic network is interpreted from the sinuosity of the contours and from the dark image tone. In forest interpretation, the decisive indicator of different tree species is the shape of the crowns. The configuration of swamps is used in judging the peats which form them. On the basis of the nature of relief forms one can indirectly determine their genesis, geological structure, and lithology.

Stereoscopic study of aerial photographs is used in determining the three-dimensional configuration of features.

The spatial position of a feature among other features makes it possible to make certain indirect deductions characterizing a feature or phenomenon. This criterion is extensively used in geomorphological interpretation. For example, a relief form (terrace) in itself as a criterion still tells nothing concerning its origin unless its position is indicated (on the seashore, in a valley).

Shadows are a fundamental clue in interpretation work and in the study of geomorphological features without a stereoscope by means of visual examination of aerial photographs and other materials from an aerial photographic survey in both forested and exposed regions. These criteria favor the visual perception of different photo patterns of the relief image associated with the erosional dissection of the surface and make it possible to detect all very small relief irregularities.

Such features as gullies, rills, precipices, landslides, terraces, etc., are expressed by shadows. The slopes of highlands or depressions show up well due to different illumination. Slopes facing the sun have a lighter tone, whereas the opposite slopes are shaded, giving the impression of relief without a stereoscope. This criterion can be used in distinguishing types of mountainous relief, hilly relief can be distinguished from lowland relief, and different microrelief image patterns can be discriminated.

A shadow covering the side of a feature opposite to the sun is called the shadow proper, whereas the shadow cast by features or objects onto the earth's surface is called a falling shadow. The first type of shadow complicates interpretation, distorting the primary shapes of objects. The second type makes it possible to judge the shape and height of objects. Shadow size is dependent on height of the object, inclination of the sun's rays (directly), and surface relief. Special tables make it possible for a definite time and latitude to determine the height of an escarpment, etc., from its shadow.

Tonal criteria. Image tone is the degree of blackening of the photographic emulsion on an aerial photograph. The entire diversity of colors on the earth's surface is conveyed on a black-and-white aerial photograph as a gray color in different tones. In actual interpretation work the tone of an aerial photograph is evaluated by eye. The following tones are distinguished:

1) very light;

2) light;

3) light gray;

4) gray;

5) dark gray;

6) very dark.

The image tone is dependent on the color of a feature, its reflectivity and degree of illumination when the photographs are taken. Panchromatic emulsions, sensitive to all rays in the visible spectral region, are usually employed for more correct color rendition.

Objects reflecting rays in the visible part of the solar spectrum appear in a light color on the photographs, whereas objects absorbing a large part of the rays incident on them appear in dark tones. The image is also dependent on the natural color of the objects. For example, vegetation with a green color scatters green, yellow and in part red spectral rays, and therefore has a slight effect on the photoemulsion and appears in a dark tone.

The flux of radiant energy incident on a surface can be absorbed, penetrate, /12
or be reflected. Reflection can be of the mirror or scattered types. The quantity of light reflected from any rock is dependent on its color, structure, and surface conditions. Even, smooth surfaces which do not scatter light and do not reflect it into the camera objective will appear in a uniform light color. On photographs solonchaks, chalk, limestone, and dry sand have a light tone. Chernozem and highly moistened peat absorb a high percentage of the incident rays and appear dark on the photographs.

If rocks are exposed at the earth's surface their different reflection coefficients cause a different blackening of the negative emulsion during an aerial photographic survey of the region. This property of aerial photographs is used extensively in geological interpretation.

In addition to the reflectivity of natural features, the image tone is affected by time of the survey and the quality of the photomaterials. The basic condition is the perception of contrast, blackening differences. Haze, fog and aerosol particles are harmful for a survey and reduce contrast. Contrast is also reduced in early spring and late autumn when the soil is very moist.

The photo image pattern is a regular combination of the direct interpretation criteria characteristic for any object or sector of the earth's surface. The photo pattern expresses primarily the microrelief and surface dissection, but also forest cover, surface moistening and reflectivity of natural formations. The structure of the photo image pattern may vary greatly: spotty, banded, striated, granular, smooth, etc. For example, work on study of the shallow waters of the Caspian Sea has made it possible, on the basis of different photo image patterns, to determine more or less accurately the rocks making up the sea floor (Sharkov, 1960, and others).

Indirect interpretation criteria. These criteria are based on deductive, logical conclusions as a result of determination of the regular interrelationships existing among different elements of the natural landscape.

For example, the lithological composition of rocks and their bedding exert an influence on the development of relief and on the nature of the erosional network. In many geomorphological regions it is possible to find an indication of a coincidence of relief types with regions of occurrence of certain rocks. For example, in the Southern Urals, I. M. Krasheninnikov (1919) defined geomorphological regions formed by limestones, salt-bearing Tertiary rocks, etc.

Under identical physiographic conditions, that is, in areas with closely similar erosional, sheetwash, weathering, and other processes, different lithological rock complexes give rise to different relief forms which to one degree or another are specific for them (this applies primarily to mesoforms and microforms, morphosculpture types as defined by I. P. Gerasimov).

A uniformity of relief forms leads to a similarity in microclimatic phenomena and also in the soil-vegetation cover. Hydrogeological conditions and the composition of unconsolidated surface deposits influence the nature of the vegetation cover.

The formation of many microrelief forms is associated with geomorphological processes (karst, thermokarst, suffosion (undermining), slumping, etc.). Making use of these relationships, on the basis of the nature of relief, erosional dissection, and types of woody vegetation, clearly expressed on aerial photo- /13
graphs, it is possible to interpret geological structure, lithology, physiographic processes, and determine the depth at which ground water is found.

Interpretation of the lithological composition, discrimination and mapping of the boundaries of distribution of rocks on the basis of a study of relief types and forms on aerial photographs, is called the aerogeomorphological method, whereas the very criteria determining the lithological composition are called (as suggested by V. P. Miroshnichenko) lithomorphogenic interpretation criteria. The criteria of dependence of relief on the nature of rock bedding (structure) are called (after V. P. Miroshnichenko) geostructural or tectomorphogenic criteria. The criteria of the dependence of vegetation on soil-ground, hydrogeological, and physical geology conditions are called phytological or geobotanical interpretation criteria.

Interpretation on the basis of lithomorphogenic criteria is based on the fact that for definite lithological types of rocks, assuming identical physiographic and structural conditions, there are definite characteristic relief types and forms. The relief forms studied in the field and on the aerial photographs make it possible to judge the lithological composition of both unconsolidated and bed rocks, and also the processes of genesis of these forms.

In many cases the configuration and distribution of micro- and mesoforms create on aerial photographs a unique photographic image which is dependent on lithology, structure and hydrogeological conditions.

The nature of the photographic image stands out clearly when the photographs are examined visually and therefore, it is possible to trace the area distribution of the boundaries between different types of soil and rocks. For example, some glacial forms of accumulative origin, morainal hills, eskers, drumlins, etc., stand out very clearly.

The most clear expression of the dependence of relief on the lithological composition of bedrock is manifested in well-exposed regions. In areas where the bedrock is buried beneath Quaternary deposits of great thickness, the relief is dependent primarily on the lithological composition of the surface deposits. In such areas the interpretability of the bedrock is poor.

Geostructural or tectomorphogenic interpretation criteria. With different dips of any rock suite the relief developing on them and reflected on the aerial photographs has a different nature (or has tectomorphogenic variants). On the basis of these types of relief we can judge the dips of rocks, their strikes, and their structures. These relationships are manifested particularly well in high-mountain regions, but in mountains with intermediate elevations and even in ridged-hilly regions it is also possible to measure rock dips.

We will take three cases of the orientation of a heterogeneous series of beds:

1) vertical (or at an angle ∠90°);
2) monoclinal;
3) horizontal.

In the first case the relief, as a result of erosion, will be represented by an alternation of barriers, outcrops of hard strata and dips, depressions between them, associated with soft strata. The aerial photograph exhibits a banded image caused by an alternation of strata having different color and reflective properties.

With the erosion of a monoclinally oriented heterogeneous series of beds we observe formation of a consequent type of erosional network (gullies, valleys) running along the strata perpendicular to their strike. The interfluves between them will have a clearly expressed triangular section (Figure 2). ∠14

The overall longitudinal profile along the strike will have a serrate-notched appearance. Accordingly, the structure of interfluves in exposed regions which have experienced denudation will appear from above as if they were formed by a great number of triangular plates superposed on one another like tiles. Those of them which were cut by gullies in hard rocks rise above the general interfluve surface; intercalations of less resistant rocks between them give rise to depressions.

V. P. Miroshnichenko has given the term "stratum triangles" to these triangular plates. One vertex of such a triangle is on the interfluve whereas the other two are in the thalwegs of the bounding gullies. The line connecting these points, if they are at the same elevation, shows the strike of the stratum, whereas the line perpendicular to it (drawn from the interfluve vertex of the stratum triangle to its base) is the stratum dip direction. The entire group of interfluve vertices of these triangles forms the water divide, whereas the lines connecting the two other vertices are the thalweg lines of the bounding gullies.

The stratum triangles forming the interfluve form a fine ribbed pattern on the photograph which reflects the microrelief. As a result of the different reflective properties of the rocks it is expressed in an alternation of bands of different hues of light and dark tone. The outlines of the plates vary in dependence on the dip of geological beds. They seem to be drawn out with a dip decrease and shortened with a dip increase.

A flat-topped residual relief is formed if the dip is 0°; if it is 90°, the relief will be represented by rows of barrierlike outcrops formed by layers of hard rocks with depressions between them passing along the soft strata. In the case of tilted bedding, the steeper the dip, the more obtuse is the interfluve vertex of the triangle; vice versa, the gentler the dip, the more acute is the vertex (elongated triangle).

Sometimes the configuration of the outcropping layers is not triangular and a stratum trapezium or semiellipse is observed instead. These are the same triangles which are formed in rocks with a reduced antierosional resistance and therefore they have indistinct, smoothed outlines. They also can be used for geological interpretation, the same as stratum triangles. When the investigator has a certain amount of experience the dip can be determined with an accuracy to 5-10° from the nature of the stratum triangles.

On aerial photographs in many cases it is possible to determine not only the bedding elements of strata, but also the folds, their types and the nature of the spatial outlines. Attention must be given to the relative arrangement of stratum triangles in order to determine the nature of a fold. If within the area covered by the aerial photographs the interfluve vertices of all the stratum triangles are turned in one direction and the lines connecting them along the strike do not form a closed contour, we therefore have a monoclinal bedding of the suite. If the vertices of the stratum triangles face one another and the lines connecting them form a closed contour we have an anticlinal fold (Figure 3).

The type of fold can be determined from the nature of the stratum triangles on its slopes. If the stratum triangles are of the same type on both slopes we have an upright fold. If on one slope there are short stratum triangles or even /15
stratum barriers, whereas on the other slope there are elongated triangles, an

oblique asymmetrical fold is present. If on a fold slope a stratum-residual relief element is replaced by a stratum triangle, and then by a stratum barrier formation, this means that the slope is becoming increasingly steeper.

In horizontally bedded strata with erosion and denudation of the surface the strata outcrops form closed lines situated at the same elevation and "stratum remnants" are seen in the photograph pattern (Figure 4).

By studying the structure of a region in such a way from a large number of photographs, it is possible to trace the bedding conditions of strata, their strike, folding, and undulation of folds. Photogrammetric methods can be used in determining the elevations of points on the slope or base of the component strata and geomorphological profiles can be compiled for maps.

Tectonic contacts formed by the noncomforming bedding of cross-sectional strata (faults, thrusts) are reflected on aerial photographs in the form of displacements of the lines of outcrops of strata or sometimes by a sudden change in the photo image pattern, along straight or slightly curved lines. Sometimes they appear on the photograph as a sharp contact between light and dark tones. For example, the trans-Caspian dark tone is produced by dark green sandstones of Albian age in contact along a fault line with light-colored sandstones of the Upper Barremian. A ravine or valley may be incised along the fault lines.

In the region of stratified calcareous rocks in Central Siberia, faults are reflected on aerial photographs in the form of well-expressed straight lines which disrupt the regularity of the banded photo pattern. Trap dikes are observed locally along the fault lines.

The possibility of detecting recent tectonic structures (arches, domes, faults) in regions filled with thick strata of recent unconsolidated Quaternary deposits is of very great importance. The concentric arrangement of types of vegetation, the radial pattern of the erosional network, and the presence of sandy eolian formations made it possible to detect a whole series of recent structures which may be petroleum- and gas-bearing.

As pointed out in studies by V. P. Miroshnichenko and B. V. Vinogradov, in the Caspian Lowland of Western Turkmenia, the layout of the hydrographic network, solonchaks and takyrs, and eolian forms exhibits a close dependence on recent movements of the earth's crust and on ancient and buried geological structures, whose detection by surface methods is very difficult.

It goes without saying that the use of the above-mentioned interpretation critieria is dependent on local conditions. Accordingly, in the interpretation of photographs for a specific region, the first step is a preliminary interpretation of clues by checking on the ground and compiling tables of reliable interpretation criteria for all the geomorphological and geological features shown on the map together with an appendix of their characteristic photo image patterns and indications of the conditions under which the survey was made (season, day, weather).

Geobotanical (phytological) criteria have come into very active use in the USSR aerogeological service. Types of vegetation cover are studied as indicators of features of interest to geologists, hydrogeologists and geomorphologists. Geobotanical indication methods make it possible to use the nature of the vegetation in judging other regional conditions: relief types, geological structure, and ground water. One of the most clearly defined directions in the use of geobotanical criteria is in hydroindication interpretation, the interpretation of hydrogeological conditions and ground water from aerial photographs on the /16 basis of the vegetation cover. In arid desert regions vegetation in many cases is clearly indicative of ground water accumulations, particularly during the dry season (Viktorov, 1955, and others). In the deserts of Central Asia (Karakumy, Kyzylkumy) growths of black haloxylon are the most distinctive indicator of ground water accumulations at shallow depths, that is, accumulations most convenient for water supply. Their height, degree of branching, and crown density are governed by the depth of ground water. A dark spot formed on a photograph by a growth of haloxylon is readily detected and hydrogeological drilling is undertaken on the basis of interpretation data. Sometimes haloxylon growths make it possible to trace the direction of ground water flow, particularly on the ancient alluvial plains of the Amu-Dar'ya and Syr-Dar'ya. Large growths of black haloxylon stand out on aerial photographs along channels with ground water flow, bordering them in the form of dark bands. On the other hand, growths of black haloxylon and tamarisk die out along dessicated channels.

Vegetation can give an idea concerning some present day processes transpiring in arid soil and ground cover regions, such as gypsum accumulation processes.

Here lichens are important indicators; on aerial photographs their dark-colored associations indicate the presence of gypsum in the desert surface material.

Some authors have indicated that the presence of tectonic dislocations is expressed in a very definite way in the vegetation cover. In Eastern Fergana, the grouping of moisture-loving plants forms a strip which extends along a major fault in Quaternary deposits. This strip of bright green vegetation stands out sharply against the homogeneous desert background and this made it possible to trace the direction of a dislocation without difficulty both on the ground and on an aerial photograph. In Southern Fergana, a study of aerial photographs revealed the presence of dark sectors on the floors of dry valleys which resembled bridges. These were found to be patches of moisture-loving vegetation in those segments of the channel where a ground water backwater was created due to the accelerated growth of folds.

In aerogeological interpretation, it is recommended that attention be given to the overall vegetation cover pattern and that all elements having a linear nature be discriminated in this patterm because regular boundaries and geometrical trueness of configurations are not characteristic of natural plant communities. Dark bands caused by the presence of halophytes are noted on aerial photographs for the trans-Caspian area along lines of tectonic dislocations in takyr gypsum-bearing and calcareous clays occcurring amidst sands.

Marine terraces of different ages are interpreted in the Caspian Lowland on the basis of geobotanical criteria:

1) a terrace of Late New Caspian age is interpreted from the spotty photo pattern created on it by an alternation of associations of halophytes (light-colored spots) and shvedok-azhrek*(dark spots);

2) a terrace of Early New Caspian age is discriminated from the growth of Halocnenum, giving a gray image tone, with azhrek associations in the depressions, characterized by small dark spots;

3) a terrace of Upper Khvalynskiy age is interpreted from complexes of tall grass-white wormwood associations and Anabasis salsa Bent. on low hills, alternating with Halocnenum associations on clayey loam sediments along the periphery of intermittently dessicated salt lake depressions;

4) a terrace of Lower Khvalynskiy age is interpreted from a complex

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*Translator's Note: shvedok = Suaeda confusa; azhrek = Aeluropis litoralis.

of black wormwood associations and mixed grasses, alternating with quack grass associations in lagoon-like depressions.

River valley deltas of different ages, such as in the lower course of the Ural River, are readily interpreted on aerial photographs on the basis of /17 different steppe plant communities which create different photographic tones and photo patterns.

The method for interpreting forest vegetation in different landscape-geographical regions has been well developed so that aerial photographs can be used in practical forestry. Forest vegetation is interpreted from the clearly granular structure of the photo pattern, a dark or dark gray tone, which consists of the images of the projections of the crowns, the gaps between them, and shadows. Areas without forests (meadows, swamps) do not have a granular structure, that is, are characterized by a smooth (or cellular, etc.) structure of the photo image. Aerial photographs at large and intermediate scales can be used in judging the types of forest and this can serve as a marking criterion for distinguishing relief forms and their structure. Pine forests, distinguishable on aerial photographs, grow on sandy, well drained soils and are frequently associated with accumulative relief forms such as eskers, kames, lake and river terraces.

On aerial photographs a pine forest has a light gray image tone. At scales from 1:15,000 to 1:25,000 the configuration of the projections of crowns is round or oval. The gaps between the crowns are identical and of a dark tone. Under the stereoscope the crowns seem to uplift above the ground. Differences in height are not well expressed.

In the forest zone, spruce and mixed forests are characteristic of loamy and clayey soils. Spruce forests have a dark gray image tone. The conical configuration of the crowns is well expressed only on aerial photographs at 1:5,000. On aerial photographs at 1:10,000 to 1:15,000, it is irregularly rounded; at 1:25,000 the crowns have a fine rounded shape. The canopy height difference and presence of gaps are clearly expressed. The shadows have a pointed, conical configuration.

Pine-spruce forests are characterized by a marked difference in the size of crown projections and tone qualities; the difference in height is well expressed.

The projection of birch crowns is round (at 1:10,000 to 1:25,000). The difference in height is insignificant. The crowns are denser than for pine. The distance between crowns is small. The shadows are oval, egg-shaped.

Moisture-loving grasses are interpreted on aerial photographs from their dark image tone; they are usually associated with low-lying swamps or appearance of springs at the surface.

Types of forest can be used in differentiating lithological varieties of rocks of different genesis. For example, in the northwestern part of the Russian Soviet Federated Socialist Republic, pine-lichen associations are associated with eluvial-talus gravelly deposits of crystalline rocks, pine forest-sphagnum moss associations are found on peats underlain by light clayey loams of glaciolacustrine genesis, a bilberry-broad grass association is found on rubbly glacial sandy loams, etc. In the Western Ukraine, geobotanical criteria are used in differentiating the following by lithology and origin: alluvial and proluvial deposits in depressions, characterized by a black alder-mixed grass association, Neogene sands characterized by pine forest mixed with beech and hornbeam, etc. On the basis of a spotty photo image pattern, caused by an alternation of microdepressions with dense meadow vegetation on clayey loams and sand hills with a thin vegetation cover, it is possible to interpret terminal moraine deposits in this area without difficulty. In the absence of vegetation or when there is a thin pine forest cover, it is possible to interpret fluvio-glacial sands, forming dunes [Poles'ye].

Plant associations are frequently indicators of lithological rock varieties in the Southern Urals. For example, plant associations differentiate sectors with serpentinites, gabbros, brecciated rocks, and unconsolidated Quaternary /18
deposits.

The vegetation cover is sometimes a criterion making it possible to interpret individual relief forms having inadequately distinct criteria. For example, in forested regions sinkholes may be poorly visible on aerial photographs, but are indirectly shown by the depressions formed by the tree canopy, if the trees in the forest are identical in height. In mountainous forested regions, places lacking forest vegetation are associated with areas characterized by eluvium with large fragments and talus.

The arrangement of forest vegetation on an aerial photograph in the form of arcs, rings, bands and lines is usually associated with peculiarities of geological structure. For example, in the Western Ukraine, tectonic dislocations are easily interpreted from the linear distribution of swamps and dense pine forest. Clustering of woody vegetation in the mountainous forested regions of Central Kazakhstan clearly emphasizes the lines of disjunctive dislocations and fracturing.

In tundra permafrost areas clumps of scrub and forest are frequently associated with runoff depressions and sectors with deep permafrost. Thermokarst basins in this area are interpreted readily because trees do not grow on thawed sectors.

Geobotanical criteria are basic in interpreting swamps. Forest vegetation reacts sensitively to excess stagnant moistening of soil. When the ground water level is high, trees have a thin crown and a lesser height and in many swamps the forest disappears and is replaced by moisture-loving grasses and mosses.

Technogenic, anthropogenic and zoogenic criteria, the result of different forms of activity by man or animals, in some cases can also be used as indirect interpretation criteria. The distribution of cultivated areas, roads, and populated places is closely associated in built-up areas with the geological-geomorphological conditions of the region. For example, these criteria are used in interpreting types of glacial landscapes in the western part of the Russian Soviet Federated Socialist Republic. Marmot holes and termite hills, creating a characteristic surface photo image pattern, can be used in interpreting surface deposits and soils, such as the loessial deposits in the southern part of Western Siberia.

Finally, it must be noted that during recent years, with application of the landscape interpretation method, the concept of indirect criteria is frequently being replaced by the concept of use of a complex of natural indicators of the studied features (landscape components). For example, the forms of glacial relief, structure of the erosional network, swampy areas, and forest types can be indicators (indirect criteria) of the distribution of different genetic types of Quaternary deposits, etc.

STEREOSCOPIC PROPERTIES OF AERIAL PHOTOGRAPHS AND THEIR IMPORTANCE IN GEOMORPHOLOGICAL INTERPRETATION

The interpretation of aerial photographs, depending on the place where it is done, can be classified as field and office.

The office interpretation is done by means of an analysis of the aerial photographs and is based on the fact that the photographic images of geomorphological features and their combinations have singular interpretation criteria characteristic of them alone which make it possible to describe these features.

Interpretation can be classified as visual and visual-instrumental, depending on the method employed in studying the photographic images. Visual interpretation is done with the naked eye. Visual-instrumental interpretation of aerial photographs is done using instruments which give a three-dimensional terrain image, allowing measurements to be made on the aerial photographs: /19

a) magnifying glasses with 2^x magnification and a large field of view (10-12 cm), making it possible to examine an aerial photograph with both eyes;

b) stereoscopic eyeglasses;

c) the "Tsiklop", "STD", and other stereoscopes;

d) celluloid parallax measurers, permitting measurements with an accuracy to 0.1 mm.

More complex and precise measurements of the three-dimensional terrain model are made with stereometers, stereocomparators, multiplexes, and other special instruments.

During recent years experiments have been made with the automatic machine interpretation of aerial photographs on the basis of different phototone, optical image density, and their other properties, but this method has not yet come into wide use.

Geometrically each aerial photograph is the central projection of the earth's surface onto the photograph plane. The center of projection is the rear nodal point of the objective (S). The distance from the center of projection to the photograph plane is called the camera focal length (f). On the basis of camera f, objectives are classified as long focal length (f = 200 mm or more), normal (f = 100-200 mm) and short focal length (f = 55-100 mm).

The base of the perpendicular dropped from the center of projection onto the photograph is called the principal point of the photograph (O). In actual practice the principal point is found by the intersection of the two straight lines connecting the fiducial marks printed on the edges of the aerial photograph. The principal ray of the photograph or the optical axis of the camera passes through the principal point and the center of projection.

The position of the principal point and the camera focal length constitute the elements of inner orientation of the aerial photograph or camera which determine the position of the beam of projecting rays relative to the aerial photograph plane. In order to orient this beam spatially at the time of photography, it is necessary to know the elements of outer orientation: coordinates of the center of projection XYZ (H), angle α between the principal ray (optical axis) and the vertical, angle A, the azimuth of the survey direction line (azimuth of projection of the principal ray onto the horizontal plane), and angle of turn (κ) of the photograph in its plane about the principal ray.

On a near-vertical photograph all the horizontal parallel lines appear as a system of parallel straight lines, whereas the perpendicular lines appear as a fan of straight lines converging at the principal point. On a near-vertical photograph the image of flat terrain will be plane and the contours of features on the aerial photograph will be similar to the corresponding terrain features. The scale of a near-vertical aerial photograph of flat terrain is constant and equal to f/H.

Since in actuality the aerial photograph plane is not strictly horizontal, this causes aerial photograph distortions. The displacements of points caused by aerial photograph tilts occurs in directions passing through the point of zero distortions (C). It is found on the prime vertical of the aerial photograph at a distance $f \tan \alpha/2$ from the principal point. At the point C, the angles formed by the directions passing through this point are not distorted by /20
aerial photograph tilt. The prime vertical of an aerial photograph is the track of the interjection of the aerial photograph by the vertical plane passing through the camera optical axis.

The scale on an oblique aerial photograph varies. On the contour passing through the point of zero distortions, it is equal to the scale of a near-vertical photograph; toward the upper part of the aerial photograph it decreases to infinity and downward from the line it increases to unity. However, with a deflection of the optical axis from the vertical up to 3-5° the survey scale changes insignificantly and it is assumed equal to the scale of a near-vertical aerial photograph.

In addition to tilt distortions, the photograph points are also displaced due to relief in the directions passing through the nadir point n, also situated on the prime vertical at the distance $f \tan \alpha$ from the point O.

The relief displacement is

$$\delta_h = \frac{rh}{H},$$

where

h is the relative elevation of the point;

r is its distance from the nadir point;

H is survey altitude.

In mountains these distortions attain a considerable value, the moreso the lower H and the greater the variations in altitude.

On near-vertical aerial photographs ($\alpha = 0$) the point of zero distortion and the nadir point coincide precisely with the principal point.

The relief error δ_h, which is 0.2 mm or less, in actual practice is usually neglected. That part of an aerial photograph on which the relief error does not exceed 0.2 mm is called the useful area of the aerial photograph. The radius of the useful area is computed using the formula

$$r = \delta_h \frac{H}{f}$$

Contact prints (aerial photographs) overlap one another and therefore they can be examined stereoscopically in pairs; this makes it possible to see a three-dimensional terrain image.

Stereoscopy is three-dimensional viewing (vision). It is based on the capacity of man with binocular vision (the two human eyes are approximately identical) to fuse two images of an object into one and perceive an object three-dimensionally. The stereoscopic principle is the basis for measuring some linear quantities on an aerial photograph which are associated with horizontal distance on the ground or the positioning of points in the model relative to the survey air base or the observer's eye base. Hence, we have the concept of stereophotogrammetry, measurement of a three-dimensional light record.

We will assume that an observer attentively examines a point A in space and its image is registered on the observer's retinas. If between the eyes and the point A we place photographs or diagrams with identical images of this point in the form a and a' the images of A remain on the retinas, as before, although in actuality it did not exist. This phenomenon can be attributed to man's capability for binocular vision, fusing two images into one and perceiving objects three-dimensionally. This capability is constantly used in the interpretation technique.

The aerial photographs are placed at the best viewing distance from the observer's eyes, 25-30 cm, and shifted until the sighting rays intersect at the point A and form the parallactic angle $\angle\varepsilon$. It must be in the visual plane passing through the observer's eye base. It is clear that for points situated closer to the observer the angle $\angle\varepsilon$ will be larger. In the presence of a multiplicity of photograph points a three-dimensional perception of the object model is obtained. /21

Linear (measurable on the aerial photograph) parallaxes correspond to angular parallaxes ($\angle\varepsilon$). The difference in parallaxes makes it possible to judge the difference in elevations between individual points in the stereomodel and it is then possible to identify different landscape elements: trees, escarpments, beach barriers, etc.

In this procedure it is necessary to adhere rigorously to the proper layout and relative orientation of the photographs. For the left eye, the left photograph, for the right eye, the right photograph. The initial directions of the aerial photographs must be parallel to the observer's eye base. This results in the maximum stereoeffect.

With the reciprocal rearrangement of the aerial photographs or rotation of the aerial photographs by 180° one obtains a reverse or pseudostereoeffect (the valleys appear to be mountains). It is easy to obtain a stereoeffect when a stereopair of aerial photographs is studied under a stereoscope. However, it must be remembered that in this case there is an exaggeration of the relief proportional to the ratio 250 mm/f. Accordingly, the shorter the f, the more sharply expressed is the relief viewed under the stereoscope. When taking photographs with a camera having $f = 50$ mm the relief forms will appear five times higher than in reality.

Parallax measurements. The linear stereoscopic parallax p is the distance between two images of identical points measured in the coordinate system of a pair of aerial photographs.

The p value can be measured by two methods.

Nonstereoscopic method:

1) the principal points or contour points situated close to them are found on the stereopair and these are used as the origins of coordinates O and O';

2) the point identical to the right center is identified on the left aerial photograph and the point identical to the left center is identified on the right aerial photograph;

3) straight lines are drawn between the points on the left and right aerial photographs and these are used as the X-axes (initial directions);

4) a perpendicular is dropped from any identical points a and a' of the aerial photograph onto the initial direction in order to find x_a and $x_{a'}$;

5) a compass and scale rule are used in measuring the corresponding x and x' values and a formula is then used in determining linear parallax

$$p_a = x_a - x_{a'};$$

6) the relative elevation of the point is determined using the formula

$$h = \frac{H}{b} \Delta p,$$

where

H is survey altitude, in m;

b is the photographic base, in mm (distance OO');

Δp is the increment in parallaxes.

The accuracy of this method is 0.2 mm.

Stereoscopic method. The difference in linear parallaxes of points is measured on a stereometer or stereocomparator. Its accuracy is ten times greater (up to 0.02 mm). This method is used in the office when there is a photogrammetric laboratory or room.

INTERPRETATION OF ACCUMULATIVE AND SCULPTURED ACCUMULATIVE RELIEF ASSOCIATED WITH QUATERNARY SURFACE DEPOSITS

/22

Quaternary deposits occur everywhere, these being the most recent and almost unconsolidated geological formations; their thickness is highly variable: from a few (2-3 m) to tens and hundreds of meters. The relief associated with Quaternary deposits can be accumulative in genesis (terminal moraines, eskers), sometimes with correlated sculptured forms (cirques, troughs), or sculptured accumulative relief (terraces, dunes, etc.). These relief forms develop in dependence on the distribution of larger forms on the earth's surface, governed by the peculiarities of geological structure. However, on aerial photographs at the used scales they are usually interpreted in relation to the Quaternary deposits of different genetic types forming them.

In studying the Quaternary deposits which everywhere make up the earth's surface a factor of very great importance is the close interrelationship between their genesis, lithological composition, and physicomechanical properties, on the one hand, and the relief features which they form, on the other. This can be attributed to the relative recentness of Quaternary deposits and the good preservation of their accumulative relief. Accordingly, in the interpretation of Quaternary deposits the most important role is played by lithomorphogenic interpretation criteria.

In most regions where Quaternary surface deposits are quite thick (plains of the northern and northwestern Russian Soviet Federated Socialist Republic, foothill regions of downwarps) these deposits are soil-forming materials (morainal and fluvioglacial deposits, loesses, etc.). Here the composition of the Quaternary deposits exerts an enormous influence on the nature of the soil and vegetation cover. Accordingly, the next important place in study of the Quaternary cover is occupied by geobotanical (phytological) and tonal interpretation criteria.

A criterion of great importance is the spatial interrelationship of Quaternary relief forms, such as: the successive arrangement of ground moraine, the arc of terminal moraine ridges, and outwash plains. These make it possible to judge the alternation of Quaternary deposits forming them. Another example can be the position of the alluvial sandy deposits of the pine forest outwash plain terrace along a river valley.

In investigating Quaternary deposits and their tectonics it is necessary to study the boundaries of ancient shorelines of seas and lakes, marine, river and lake terraces, and for this it is very important to determine their relative elevations from aerial photographs; this is possible when stereophotogrammetric methods are employed.

Quaternary deposits (other than those in the high mountains) can be classified into the following groups on the basis of their spatial distribution.

1. Deposits on elevated interfluves. In the glacial zone these include for the most part glacial and fluvioglacial deposits, as well as covering formations; they form accumulative complexes of corresponding relief types. Formations of the eluvial group and loesses occur extensively in the extra-glacial zone.

2. Deposits on sloping surfaces. These include slide material, creep-solifluction material, gravitational and landslide deposits forming corresponding relief forms on slopes.

3. Deposits in large valleys, basins and depressions. These include /23 alluvial sediments of different facies, marine and lacustrine sediments, peat-bog formations, and the complexes of corresponding relief forms associated with them. Eolian formations also occur most extensively in these same areas.

I. Interpretation of deposits on elevated interfluves.

Glacial deposits and the accumulative relief forms associated with them have the broadest occurrence over the territory of the USSR. They form the extensive areas of the main interfluves of the northern and northwestern parts of the European USSR and Western Siberia and were formed in foothills and mountain regions which experienced ancient glaciation: Caucasus, Central Asia, Urals, Southern and Eastern Siberia, and Kamchatka. These deposits are represented primarily by the ground moraine and terminal moraines forming the accumulative relief on morainal plains, as well as hilly moraine, drumlin and ridged-hilly relief.

Morainal deposits consist for the most part of rubbly clayey and sandy loams, unsorted, unstratified, locally with lenses of sandy-gravelly deposits. The key criteria in interpreting morainal deposits are those associated with their meso- and microrelief forms and the distribution of vegetation types occurring on them. The ground moraine frequently forms the relief of a slightly hilly plain with surface slopes oriented in opposite directions or random hilly relief without any definite orientation, with depressions among the hills occupied by lakes and swamps.

Areas in which morainal deposits are found are interpreted in the stereoscopic study of aerial photographs from the configuration of morainal hills and ridges. The latter are better drained even in a forest zone usually covered with fir forests producing a dark granular photo image pattern. The sectors of depressions among hills occupied by peat bog deposits are discriminated on the basis of the interpretation criteria for swamps. They are characterized by a light tone and have a specific photo image pattern (Figure 5).

In the tundra zone the types of vegetation develop in close relationship to the degree of moistening and the permafrost characteristics of the soil (depth of the active layer). They are also influenced by the chemical composition of the soil cover, related closely to the lithology of the underlying rocks. Accordingly, here it is possible to supplement morphological criteria by phytological criteria, from which, after a number of ground control checks, it is possible to interpret the distribution of different types of morainal deposits.

In the Far North accumulative morainal highlands are frequently characterized by a finely striated photo image pattern due to erosion of hill slopes by small ravines. This pattern is emphasized by the growth of forest and scrub along the rills, whereas only infrequent larch is encountered on the highlands.

Terminal moraines were deposits at the edge of the glacier when it was in a stationary position; they frequently outline the depression of a tonguelike basin. Lithologically terminal moraines usually are relatively more sandy and contain more rubble than the ground moraine. The abundance of boulders is also an interpretation criterion. When the aerial photograph scale is greater than 1:10,000 accumulations of boulders and even individual boulders can be distinguished on an aerial photograph.

Morphologically terminal moraines are expressed as chains of ridges and hills, extending in the form of a wall, curving in an arc and oriented perpendicular to the direction of glacier movement. Sometimes there are several /24 rows of terminal moraines. Depressions are situated between them; they are occupied by lakes and swamps in the form of a dense network, intertwining like lacework (Figure 6).

The terminal moraines of mountain glaciers stand out most clearly on aerial photographs. In U-shaped mountain valleys there are rows of terminal moraine walls which extend transverse to the valley. These walls rise several tens of meters above the valley floor. Above the terminal moraine wall one observes the lakes which have been ponded by them or their remnants in the form of flat swampy areas filled with sandy-clayey lacustrine deposits.

The drumlin relief of the ground moraine is interpreted using the morphological criterion: elliptical hills oriented in the direction of glacier movement.

The forms of the sculptured glacial landscape can be seen in exhaustive detail on aerial photographs. Cirques, gigantic, chairlike forms, constitute the principal elements of mesorelief visible on the aerial photograph. Lakes are frequently observed on their floors. Cirques and cirque lakes are frequently arranged in several steps, as can be clearly seen under the stereoscope.

The overall appearance of valley glaciers is clearly visible on aerial photographs. The cirque relief of glacier valley slopes stands out clearly on such photographs. The glacier surface with a system of fissures and dark morainal strips is clearly visible.

Kame deposits are represented for the most part by stratified sands and sandy loams covered by a thin layer of sandy loam moraine. At a large scale (from 1:25,000 up) kame relief is easily interpreted on the basis of the morphological criterion: steep-sloped sand hills covered with pine or mixed forest and separated by lakes and swamps. On aerial photographs at a smaller scale kame relief has a characteristic pattern from the air resembling water ripples. It is created by an alternation of sand ridges and hills with swampy depressions between them.

Fluvioglacial deposits and their relief forms are somewhat more difficult to interpret than morainal deposits. They are usually situated in a broad train along the outer side of terminal moraines and are represented primarily by different kinds of sands and coarse gravels, subjected to strong erosion and dissection by gullies and rivulets. The deflation of fluvioglacial deposits gives rise to characteristic eolian relief forms. Pine forests grow on consolidated material.

In the broad development of fluvioglacial sands (of the outwash plain type) one usually observes large but low, smoothed forms separated by a system of shallow, complexly branching gullies. Under the stereoscope on the aerial photograph we observe very smooth relief with a dendritic drainage system, clearly depicting a decrease in the level of the vegetation cover.

Eskers have the configuration of narrow and long ridges resembling a railroad embankment with a narrow top. They are easily interpreted on aerial photographs on the basis of morphological criteria. Their sinuous configuration resembles a channel. Eskers run across lakes and swamps and are characterized by the presence of forest vegetation (granular photo pattern and dark image tone). Esker ridges can be easily mapped from aerial photographs. This is of great importance in practical field work in the search for construction materials (locations of open pits for construction sands).

Covering deposits, sandy and clayey loams (morainal derivatives), occur /25
widely (particularly in the northeastern Russian Soviet Federated Socialist Republic and in the southern part of Western Siberia). They are closely associated with glacial deposits. They lie on morainal and other formations on interfluves and slopes. On aerial photographs they are difficult to interpret and can only be identified on the basis of morphological criteria. Interfluves overlain by covering clayey loams have the nature of lowland, poorly dissected areas. Dissection of the surface by a system of tiny valleys and gullies with a narrow floor and gentle slopes can occur on the interfluve slopes. The local interfluves between them have smoothed, slightly concave profiles.

Eluvial deposits on flat interfluves and ridges are the products of weathering and leaching of bedrock by atmospheric agents which have remained at the site of their formation. They can be represented by different formations:

blocks, debris, gruss, clayey deposits, depending on the stability of the bedrock. Very frequently they cover flat-topped highlands. Eluvial deposits do not form major relief forms. Eluvial deposits are quite clearly interpreted on aerial photographs.

The eluvium of hard igneous rocks is associated with the tops of highlands and low, steep-sided hills and is represented by large clastic material; it stands out on aerial photographs because of its light and light-gray tone. The bedrock frequently seems to "peek through" the eluvial formations, indicative of their relative thinness. Eluvial deposits can be outlined stereoscopically on the basis of image tone and relief.

In plains, regions where the bedrock is covered by thin eluvial deposits, it is difficult to obtain information on the geological structure of the underlying rocks during studies on the ground. However, on aerial photographs in many cases it is possible to make a detailed analysis of the peculiarities of geological structure, since the ancient structures seemingly "peek through" the eluvial deposits due to differences in the composition and color of the eluvium itself, forming due to weathering of bedrock of different composition.

In the same way the microrelief of the bedrock locally "peeks through" from beneath the thin covering eluvium as a result of the more intensive moistening by ground water in accordance with the complex pattern of the underground hydrographic network (Petrusevich, 1962).

Loessial (hypothetical) Quaternary deposits occur most widely beyond the limits of glaciation in the Ukraine, in Cis-Caucasia, in southern Western Siberia, and in Central Asia. They mantle the interfluves, also descending onto the upper terraces of ancient valleys. Their characteristic morphological interpretation criterion is an almost ideal flatness, only disrupted by level dish-like circular or elongated depressions, obviously of an undermining-karst genesis. In the marginal sectors of elevated loessial planes there is a characteristic horizontal pattern of erosional dissection, a dendritic network of gullies and valleys with a v-shaped transverse profile, with steep, precipitous slopes and with flat-topped remnants between them (Figure 7).

II. Interpretation of slope deposits

The slopes are an element of both positive (interfluve) and negative relief forms. A study of slope relief from aerial photographs makes it possible to determine to what genetic categories of forms they belong and to characterize the deposits of slopes, their area distribution, and development along the slope profile.

Deluvial deposits of slopes are formed as a result of sheet erosion and erosion by rain and melt water acting upon the weathered products of rocks in a downslope direction and on gentle slopes are represented by sandy and clayey loam with clastic material. /26

The thickness of the deluvium is dependent on slope steepness. On gentle slopes it is rather great and increases toward the foot of the slope. In arid and well exposed regions the slopes of complexes covered by deluvium are readily interpreted from soft smoothed forms and the absence of sharp prominences. The interfluves between rills and gullies on the slope have smoothed surfaces. In mountainous taiga regions with intensive processes of frost weathering striated image patterns are very characteristic for deluvium (Figure 4). Longitudinal furrows and rills and channelless depressions (dells), directed downslope, are frequently the site for development of woody vegetation, this favoring the striated appearance of the photo pattern, particularly typical in permafrost regions. In studying deluvial deposits, attention must be given to the slope shape (concave, convex) and the degree of slope. The geomorphologist must bear in mind the great relief-forming importance of deluvial processes and in each specific case must strive to clarify the patterns of development of deluvial deposits on slopes shown on the photographs. In the Vilyuy River basin (Kornutova, 1959) the deluvial-solifluction deposits on slopes are extremely photogenic. The broad development of dells is expressed on the aerial photograph in the form of banding (striation) on the slopes.

Talus and rockfall deposits are the most common types of gravitational or colluvial deposits on slopes in mountainous regions. Talus deposits are concentrated in strips along the foot of slopes, assuming the form of fans with a vertex of facing upslope (Figure 8). In cases when talus is exceptionally well developed these fans merge at the foot as a colluvial (talus) fan or cone having a terracelike appearance. An absence of vegetation is characteristic for active talus formations. Ancient talus formations are usually covered with vegetation.

In Central Siberia (Vilyuy River basin) colluvial deposits are extensively developed on the slopes of trap plateaus and are represented by large blocks of fractured trap. On an aerial photograph they are usually expressed as a coarse granulation of the air photo image, sometimes elongated along the slope. There is no vegetation cover on these deposits.

Rockfall deposits, associated with the rapid and sporadic movement of masses on steep slopes, if extensive, can also be detected from air photos. The site of a rockfall appears in the form of light spots without vegetation without a sharp upper boundary, below which there is a hilly surface in the form of a wall or cone extending toward the foot of the slope. Rockfalls, if they block the valleys of small rivers, sometimes cause their ponding and the formation of a lake and the river itself can form a canyonlike breach with rapids and waterfalls (Petrusevich, 1962).

Landslides occur due to the displacement of part of the slope along a so-called glide plane. The principal reason for a landslide is saturation of the ground by surface or ground water and its loss of stability. Landslides can be classified as "exposed" and "concealed" or recent and ancient. On air photos landslides are identified from their association with slopes and on the basis of characteristic morphological criteria: humpiness, presence of vertical shears, cirques, and forest-stripped sectors (Figures 9, 10, 11).

The shadows of landslide scarps create a concentrically banded structure /27
of the photo image pattern. Sometimes it is possible to detect surface emergence of ground water which favors landslide formation in the form of dark discrete spots and very thin sinuous lines. Ancient landslides can be discriminated from recent landslides because they have a smoother surface and frequently are covered by scrub and forest. They can be interpreted only under a stereoscope.

At the Aerial Methods Laboratory, a group of specialists under the direction of S. S. Shul'ts has developed a method for the aerogeological study and classification of landslides in the example of the highlands along the Volga. Three principal types of landslides can be distinguished in the Volga region from the planimetric image of landslides, caused by their geological and morphological structure, age and stability:

1) cirquelike landslides, whose image has a more or less rounded

configuration;

2) frontal landslides, whose image has a configuration extending along the slope (across the movement of the landslide masses);

3) landslide flows, the image having a shape elongated in the direction of movement of the material, sometimes tear-shaped.

III. Interpretation of deposits in valleys and depressions

An erosional-accumulative complex of relief forms in river valleys and alluvial (fluvial) deposits are widely developed in all geographic zones. Air photo interpretation makes it possible to study different area patterns of the hydrographic network and their relationships to geological structure and neotectonics. Dendritic, radial and latticed types of erosional dissection, knee-bends in valleys, and the directions of their linear reaches in many cases are governed by the structure and fracturing of the component rocks.

Aerial photographs depict broadened sectors of valleys with intensive meandering, undermining of banks, and accumulation of alluvium, and sectors of relative narrowing with a v-shaped cross section with the presence of bars, rapids, and waterfalls.

In studying the cross section of a valley on aerial photographs, it is possible to distinguish the channel and the sandy-gravelly channel alluvium forming it on the basis of a light tone and characteristic forms: spits, shoals, islands, and levees. Floodplain terraces are characterized by swampy surfaces and silty soil. Within its floodplain the river meanders; here we find ox-bow lakes, cut-off meanders, and small swamps formed by peat formation in the ox-bow lakes. The process of accumulation and redeposition of alluvium is associated with channel shifting as a result of definite cycles of lateral river erosion. Its traces are expressed on an aerial photograph in the form of concentric lines which curve in different directions. They constitute bands of alluvial material deposited by the river during its retreat from the corresponding bank. Their microrelief is formed by rows of small concentric benches facing the channel. The floodplain vegetation, adhering to the patterns of alluvium accumulation, is arranged in concentric bands. Distinct outlines of channel shifting fans, levees, and swampy ox-bow lakes are very characteristic for the floodplains of major rivers.

The scarps of river terraces stand out clearly on aerial photographs; they are well expressed in the relief under the stereoscope and by shadows cast by the scarps. In many cases they are characterized by an abrupt change in the type of vegetation and the nature of the photo image pattern. The surfaces of river terraces are flat; in different valley reaches they may have different interpretation criteria, depending on their morphological peculiarities and the composition of the alluvial material and bedrock from which they are formed. Among the floodplain terraces it is the younger terrace levels which stand out /28 best; they are well expressed in the relief. Air photo interpretation of the relative elevations of terraces in different parts of a valley is of great importance.

On aerial photographs, it is easy to determine sectors of present day undermining of slopes consisting of bedrock or ancient Quaternary deposits (Figures 4, 7, 12, 13).

Interpretation criteria are established for different types of alluvium by means of field investigations, particularly in regions promising with respect to mineral placers.

The accumulative relief of proluvial deposits (alluvial fans) is associated with the erosion of small particles of eluvium and deluvium by intermittent watercourses. The deposits of intermittent watercourses and debris cones are poorly sorted, consisting mainly of rocks and gravel. Proluvium (alluvial fan material) is transported from the slopes and deposited on the piedmont plain or in a broad river valley in the form of a broad, gently sloping fan. These cones or fans vary in width from 20-30 m to several kilometers.

River valleys, cutting through proluvial formations (alluvial fans) and becoming incised in the bedrock, locally form characteristic proluvial terraces with bedrock frequently outcropping at the base.

On aerial photographs proluvium is identified from its fanlike form and the presence of a great number of channels of intermittent watercourses which dendritically intertwine with one another; they appear on the aerial photographs as light bands.

Two types of fans can be distinguished: active alluvial (proluvial) fans whose growth process is continuing; their surface, like deltas, is incised with an intertwining network of intermittent channels; woody vegetation is poorly developed on these fans or is absent; there are also stabilized alluvial fans which have poorly expressed contours, in large part covered with forest or steppe vegetation.

The sculptured accumulative relief of eolian deposits is a result of the erosional-accumulative activity of the wind. Lithologically these deposits are represented primarily by well-sorted sands. They are formed as a result of the eolian reworking of deposits of different genesis. They occur extensively along the sandy shores of seas and lakes and on the sandy terraces of large rivers. Large areas of such deposits are found in desert regions with a thin vegetation cover. They are interpreted on the basis of characteristic microrelief forms: presence of hills, ridges, dunes and barchans of typical structure.

On aerial photographs barchan sands stand out in the form of crescent-shaped spots of a light color, oriented in some one direction (usually perpendicular to the direction of the prevailing wind). Ridged, hilly and "honeycomb" sands (Figures 13, 14, 15, 16) also give a characteristic photo image pattern. Dunes in forested regions are easily determined from the light color of the dune ridge as a result of exposure of deflated sands.

Eolian deposits held in place by vegetation, and exposed deposits, still being deflated, can be distinguished. Sandy eolian deposits without vegetation stand out on an aerial photograph because of their light gray or white photo tone, close in color to a snow surface. In the forest and wooded steppe zone eolian deposits are frequently covered by a pine forest.

Marine and lacustrine Quaternary deposits are usually observed in a relatively narrow coastal zone and are interpreted on the basis of a characteristic combination of relief forms: abrasion benches, terrace surfaces, presence of barrier beaches and dunes. The relief forms are of a sandy composition: spits, barrier beaches and bars are interpreted on the basis of their /29 light photographic tone and typical contours (Figures 9, 15, 17, 18).

Chemical Quaternary deposits are also frequently observed here. They are associated with depressions occupied by solonchaks (salt lakes which are intermittently dry). They are characteristic for excessively moist depressions in an arid climate and are formed as a result of the capillary rise of highly mineralized ground water. Upon desiccation the solonchaks become hard, crack, and salt encrustations appear on the surface. After a rain the solonchaks are impassable. They are readily interpreted from their light image tone with dark spots, representing excessively moistened sectors. For example, these include a former gulf of the Caspian Sea, the Mertvyy Kultuk, etc.

Interpretation of swamps and Quaternary peat bog deposits. Swamps are those parts of the earth's surface which most of the year are excessively moist. Under these conditions there is an incomplete decomposition of plant remains and peat accumulation. Swamps with a peat thickness less than 0.5 m are called swampy lands. Swampy landscapes occupy enormous areas; this is caused primarily by climatic and geomorphological conditions. In the northern and northwestern European USSR and in some regions of Western Siberia swamps occupy more than 40% of the area. Their role is exceptionally great in man's economic life.

The study of peat bog deposits is of great theoretical and practical interest for specialists in geomorphology and Quaternary geology. The theoretical study of the thickness and composition of peat, as well as the pollen which is beautifully preserved in peat horizons, enables us to form some idea concerning the paleogeographic conditions, primarily of postglacial times preceding the present-day period. A swamp is a singular geographic landscape in which exogenous geomorphological processes of present-day relief formation occur completely differently than in nonswampy sectors of the same region.

Swamps on aerial photographs can be interpreted using a number of direct and indirect criteria. On aerial photographs there is a direct reflection of the vegetation cover (woody or grassy) in the swamp, the degree of surface inundation, hydrographic network, microrelief, and planimetric outer boundaries of the swamp area, that is, its shape. In addition, on the basis of a number of indirect criteria a whole series of swamp area characteristics can be distinguished: interfluve or valley types, headwaters or lower reach position, marshes, etc.

For example, lower reach swamps are characterized by an absence of woody vegetation and presence of an internal network of channels of a ribbonlike, fanlike, or elongated form. The internal channel network can be represented by small rivulets and march formations with through flow. The headwaters stage in swamp development is characterized by a slightly concave form, occupancy of the swamp by pine, and absence of a channel network. These swamps are associated primarily with glacial landscapes (ravinelike depressions, elongated runoff depressions, ancient glacial water bodies).

In swamps the vegetation is always depressed. This is reflected in the thinness of the forest, a decrease in crown diameter, and a lesser height of the trees. Accordingly, the granular structure of the photo image pattern in a wooded swamp will be finer and have a lighter tone than in the surrounding areas. Completely unforested (open) swamps will have a smooth surface with different tone properties. Their boundaries will be quite distinct amidst the forested surroundings.

If moistening is nonuniform in different parts of swamps the tone will be /30
spotty. Dark spots will correspond to negative forms of microrelief with a high ground water level; light spots will correspond to positive forms of microrelief with a lower ground water level. Ridges and swampy meadows are expressed by a special pattern structure in the form of alternating dark and light bands. If the light bands are narrow and the dark bands are broad, this means that the percentage of area occupied by ridges is less than the area occupied by swampy meadows. If the tone difference between rises and depressions is very sharp, that is, the ridges are white and the swampy meadows are black, this means that the ridges may rise 50 to 70 cm above the swampy meadow surface and the meadows are flooded throughout the year. Marshes with a through flow have the appearance of broad dark bands or cones with the broad part facing the swamp periphery. Streamlets appear as sinuous bands or as black dots arranged like beads, directed toward one of the external water outlets (Figure 5).

Many geomorphological processes are associated with the development of permanently frozen ground (permafrost), which occupies more than 47% of the area in the Soviet Union (thermokarst, hummocking, ground flow, solifluction, polygonal soils). A change in the thermal conditions in ground solidified by permafrost results in the formation of special relief forms: subsidence areas, cave-ins, swales, small, flat-bottomed depressions, solifluction terraces, hummocky marshes (swamps), all of which show up well on aerial photographs. Hydrodynamic processes associated with seasonal freezing give rise to hilly forms with ice nuclei (hydrolaccoliths).

On aerial photographs it is easy to interpret lacustrine thermokarst forms from a pattern of dark spots of various sizes and shapes, as well as small spots which are swampy meadows. In many cases they are associated with definite relief elements (such as a second terrace). Thermokarst, swales and flat-bottomed depressions stand out well, having an image characterized by small spots. In depressions the forest is absent and they are swampy.

On gentle slopes in permafrost areas there is a characteristic striated pattern caused by the linear distribution of vegetation along the runoff channels of water flowing downslope over the permafrost layer.

In northern permafrost regions, frost cracking and solifluction are the most characteristic processes. The polygonal microrelief forms which occur extensively in the arctic tundra can be studied on an aerial photograph, as demonstrated by studies made by the Permafrost Institute; on an aerial photograph it is possible to determine the shape and size of the polygons, the stage in their development, and association with various large relief forms. Solifluction micro- and mesorelief forms (benches, bands of flow origin) create a characteristic surface pattern caused by the distribution of different types of plant associations accompanying different microrelief elements.

Southern regions with permafrost are characterized by thermokarst processes associated with the thawing of ice, subsidence areas, and cave-ins. Thermokarst forms are represented by lakes, swampy swales, elongated and flat-bottomed depressions.

Study of processes in permafrost areas is of great practical value in addition to being of scientific interest. Solifluction forms are indicative that an area is ill suited for economic exploitation, for industrial and civil construction. Thermokarst is indicative of a high ice content of soils and rocks and buildings constructed on thermokarst can experience serious deformations.

INTERPRETATION OF DENUDATION-STRUCTURAL AND DENUDATION-TECTONIC RELIEF DEVELOPED ON DIFFERENT TYPES OF SEDIMENTARY AND MAGMATIC ROCKS /31

As a result of weathering and rock denudation different relief types and forms appear, depending on the different mineralogical composition of the rocks, their bedding conditions, and the predominance of different denudation agents under definite landscape-geographical conditions (Figure 9). Depending on their age and genesis, sedimentary rocks form different combinations of cemented and unconsolidated strata in nature. The strata differ at the top and bottom (bedding planes), in thickness (apparent and real), and also in strike, direction and dip. The structural elements of sedimentary rocks also include synclinal and anticlinal folds and breaks in the continuity of strata. Sedimentary rock strata (clays, shales, limestones, conglomerates) differ in hardness and color. In many cases, highlands are associated with outcrops of resistant hard strata and valleys are associated with the presence of unconsolidated rocks.

Resistant strata form steep slopes and escarpments in the relief, whereas soft, smoothed relief forms (Figure 4) are characteristic for strata slightly resistant to weathering.

The percolation of water leads to the restriction of surface erosion in permeable rocks in an arid climate. Accordingly, within the areas of their occurrence there is a coarse sharply expressed pattern of erosional dissection. A fine, fragmented pattern of erosional dissection is observed on impermeable clayey deposits.

In many cases, thick strata of limestones and dolomites form angular relief forms with slight erosional dissection. Relief on these rocks has a massive coarse appearance. Strata of hard sandstones and quartzites reveal similar characteristics. On the other hand, shale clays and marly rocks are characterized by gentle relief forms with rounded peaks, smoothed slopes, and broad valleys.

Karst phenomena form when water dissolves permeable rocks (limestone, gypsum, dolomite, rock salt). The most characteristic forms of karst relief are karst depressions (flat-bottomed depressions, funnels, sinkholes, channels). The forms of karst microrelief are clearly expressed on aerial photographs. The appearance of sinkholes, when they are not occupied by woody vegetation, produces an image structure of small spots. Under the stereoscope it is easy to see closed depressions and sometimes clusters of lakes (Figure 19). Ancient sinkholes, overgrown with forest, are expressed on photographs as rounded depressions formed by the tree tops.

Suffosion (undermining) phenomena, associated with the outward transport of fine soil material by flow from pulverized sandy-clayey strata, are usually associated with interfluves, brows of slopes and terraces. Morphologically, they are expressed by funnels and sinkholes which appear on aerial photographs as rounded white spots or dots.

Lithomorphogenic criteria have made it possible to interpret extensive areas of occurrence of sedimentary rocks in Central Siberia (Kornutova, 1959).

1. Coarse gravels, sands and clays of the Eyskaya suite (Ng_2-Q_1) along the Vilyuy-Markhinskiy interfluve form a flat plain with a surface covered by a labyrinth of small lakes and swamps. This is responsible for the spotty photo pattern of their images, surrounded by a gently sloping bench covered with dells and characterized by a striated photo image pattern.

2. Sandstones of the marine Jurassic within the Angara-Vilyuy downwarp have /32 a hilly-ridgy relief with well-shaped valleys. Clearly expressed scarps, frequently with hard-rock precipices, surround the areas of these deposits. The pattern of the shallow river network is pinnate.

3. Limestones, calcareous dolomites, and marly dolomites of the Lower Ordovician Ust'kutskiy stage (Vilyuy River basin) are characterized by the development of steplike slopes which on an aerial photograph appear in the form of a banded photo image pattern. The banding is usually regular with a uniform density and smooth transitions from one valley to the next. Alternation of sedimentary rock strata with different colors is expressed on an aerial photograph by a banded image pattern.

In addition to the lithology of the sedimentary rocks, the nature of relief is influenced to a large extent by the nature of the bedding of strata (Figure 12). The frequent alternation of lithological rock types as a result of complex structure makes it difficult to interpret photos on the basis of lithomorphogenic criteria. Accordingly, in the interpretation process it is necessary to take into account both the dependence of relief on lithological composition and the dependence of relief rock bedding conditions. The latter tectomorphogenic criteria are most clearly expressed in well exposed regions.

The nature of dissection, characteristics of interfluves, shape and steepness of slopes in different types of mountainous and hilly relief developed on dislocated strata of sedimentary rocks, can be interpreted with adequate detail from aerial photographs and hence conclusions can be drawn concerning the genesis and age relationships of relief types and individual forms.

Erosional-denudation processes, disrupting rock strata, lead to mechanical wearing of the more resistant strata and therefore the boundaries between strata and groups of strata will be visible on aerial photographs even in a forest zone. Thus, the bedding elements of strata can be easily determined by a graphic method, described in textbooks on geological mapping, using three points in the same bedding plane. In well exposed regions, the structural forms of folds, their dimensions, steepness of the slopes, orientation of their axes, strike and fracturing, are sometimes determined more clearly on aerial photographs than on a geological map.

Using the indirect criteria on an aerial photograph considered above, it is possible to study geological structure and its relationship to types and forms of denudation relief. Even in geologically "concealed" regions on aerial photographs it is possible to observe a series of criteria expressing the appearance of tectonic movements at the earth's surface. In areas of uplifts it is common to observe straightening, deepening, and narrowing of river valleys, formation of hanging valleys, a dense network of growing gullies, draining of lake basins, degradation of swamps, and the presence of ancient shorelines of water bodies. In regions of subsidence one can observe a relative broadening of valleys, intensive meandering, swamp formation, or inundation of depressions.

In some cases relief forms associated with manifestations of neotectonics can be discriminated from aerial photographs: scarps accompanying faults, domes, downwarps, etc. Their manifestations are different under different geographic conditions and can be interpreted on the basis of different landscape characteristics: swampy area microrelief, eolian formations, takyr forms, distribution of halophytic vegetation, etc.

Disjunctive dislocations of rocks are reflected on aerial photographs in the form of straight lines or slightly curving lines, frequently impairing the uniform appearance of the surface photo image pattern. If rock strata of different composition and color come into contact along fault lines there is /33
also a change in the image tone. Along faults and zones of rock fracturing it is common to observe linearly elongated relief depressions, sometimes occupied by rivers and ravines. Parallel systems of linear river valley reaches are also associated with discontinuous dislocations and fracturing. Sometimes faults are marked by strips of denser vegetation associated with increased moisture.

Magmatic rocks occupy extensive areas in mountain regions, on ancient shields and platforms, and in regions with manifestations of recent volcanism. They are subdivided into different types of intrusive (deep) and extrusive (outflowing) rocks, differing in their structure, texture, petrographic composition, and bedding elements. In contrast to sedimentary rocks they are characterized by a homogeneous composition, absence of stratification, massiveness, uniform color tone, and development of jointing and weathering forms specific for them. These properties are expressed in the relief and microrelief as well as in the nature of the photo image on the aerial photograph.

Depending on bedding conditions, igneous rocks form batholiths, laccoliths, stocks, covering strata, intersecting and sheet veins, necks, etc. These bedding forms correspond to the characteristic forms of denudation-tectonic relief which they produce. It is easy to interpret the undulating denudation plains on ancient granite batholiths, whose fracturing is expressed on the surface by a system of lines intersecting at an acute angle ("granite lattice") (Figure 20).

Any kind of dike or vein intruded into sedimentary rocks is identified from linear elongated forms, well defined conical hills, or from the appearance of rocky ridges or walls. They differ in color from the country rock, making it possible to distinguish them on the basis of image tone. It is easy to interpret light colored quartzitic, aplitic and pegmatite veins amidst dark colored shales and granites or diabasic and porphyritic dikes amidst light colored limestones and sandstones (Figure 21). The relief developing on traps is caused by their resistance to weathering and denudation processes and the bedding elements of trap bodies (Figure 22).

Within the confines of the Tungusskaya syneclise lava (trap) plateaus stand out clearly due to marked differences in relative elevations, steep rocky scarps (from 20 to 100 m), and clearly expressed steplike slopes. The river network differs sharply in its nature in regions where traps and sedimentary rocks occur. The rivers have v-shaped linear valleys, sometimes in the form of typical canyons. Sloping trap bodies are usually expressed in the relief in the form of asymmetrical ridges. The uplifted edge of the body is usually bordered by rocky scarps. The opposite slope is gentle. The circular and conical trap bodies form circular ridges or series of concentric ridges which are distinctly expressed in the relief.

Kimberlites are ultrabasic igneous rocks formed during the explosion of gases in the earth's crust; they contain a large quantity of brecciated material and include diamond deposits. In Yakutia, one of the principal criteria for interpreting kimberlite pipes is a characteristic air photo image of definite vegetation associations accompanying their outcrops. Richer soils develop on kimberlites and their weathered products; a dense alder-larch forest grows on these soils amidst the thinly forested taiga. It is expressed on aerial photographs in a darker tone. A second criterion for interpreting kimberlites is a /34
breaking of structurally denuded scarps at places where the sedimentary calcareous strata are pentrated by the ultrabasic rock forming the pipe. This is the way in which the "Aerofotos"yemochnaya," "Akademicheskaya," and other Kimberly diamond pipes were discovered.

Liparites, trachytes and other acidic extrusives are frequently expressed in the relief by conical and sugarloaf-type highlands rising above the sedimentary rocks and on aerial photographs are interpreted on the basis of morphological criteria. Laccoliths are interpreted from the annular arrangement of the rocks surrounding them.

Aerial methods are particularly important in a study of regions with present-day and ancient volcanism. Volcanoes stand out clearly on aerial photographs: they appear as regular or slightly elongated conical forms with a truncated peak whose area is occupied by a crater having the appearance of an enormous funnel. The rise to the volcano is replaced by a sudden descent into the crater and its neck. On aerial photographs it is easy to detect the subordinate vents arising on the volcano slopes along systems of radial fissures. Hardened lava flows stand out clearly. They are characterized by a dark image tone and are without a vegetation cover. Sometimes gas vents and a dense network of fissures can be discerned.

On aerial photographs, one can observe arrangement of volcanoes along definite directions and their relationship to recent tectonic dislocations, locally having the appearance of well expressed scarps (Kamchatka). When repeated aerial surveys are made active volcanoes can be identified from changes in their morphology after eruptions.

Aerial photographs from Kamchatka and Kolymskaya Oblast recently led to the discovery of earlier unknown volcanic formations: craters, calderas, lava flows, and ancient volcanoes.

TECHNIQUES AND ORGANIZATION OF GEOMORPHOLOGICAL STUDIES USING AERIAL PHOTOGRAPHS

Geomorphological studies using aerial methods are made in three stages: preliminary, field and final.

In the preliminary preparatory stage, the regions are studied from the sources in the literature and cartographic materials and their landscape-geographical conditions are clarified. The preliminary interpretation of aerial photographs make it possible to define on aerial photographs, preliminary photo layouts, or photomosaics geomorphological regions, morphogenetic relief types, and the individual most interesting geomorphological features; these are used in compiling schematic preliminary maps and descriptions. Before beginning work the aerial photographs are laid out by flight lines (using a reproduction of a preliminary layout) and are successively studied visually and in pairs under the stereoscope.

As shown by experience, even during the first stage of the work, it is possible to solve important problems in geomorphological mapping involving the study of relief morphology, genesis, and age. On the basis of direct and indirect interpretation criteria, and also by determining some quantitative morphometric characteristics, it is possible to obtain certain information necessary for determining geomorphological structure.

1. Aerial photographs are used in determining the spatial distribution of the principal morphological relief types, their areas and the nature of their natural boundaries. Their relative positions and interrelationship and the nature of the meso- and microforms making up these relief types and their elements /35 are established. The dimensions of relief forms, relative elevations, their orientation and strike, and position relative to other landscape elements (lake basins, swampy areas, direction of prevailing winds, etc.) are also determined. These data alone make it possible to draw preliminary conclusions concerning the origin of relief types and forms.

2. Aerial photographs are used in studying the interrelationships involved in relief formation and geological structure, the overall layout of a structure

reflected in surface features, the distribution of types of denuded relief in dependence on bedding of the strata, nature of folding and faults. Manifestations of recent movements of the earth's crust in the relief and landscape of the investigated region are determined. The sites of development of volcanic phenomena are studied.

Changes in the forms of meso- and microrelief on rock suites of different lithological composition are easily determined on aerial photographs. The outlines of granite batholiths, intrusive complexes, dikes, and the types and forms of denudation-tectonic relief corresponding to them can be detected.

Air photo measurements of linearly oriented relief elements (straight segments of valleys, chains of islands, etc.) and their subsequent statistical processing with the construction of rose diagrams and vector diagrams make it possible to compare them with data obtained from the study of fracturing and other characteristics of geological structure. Surface areas formed by different genetic types of Quaternary deposits and the corresponding forms of accumulative and sculptured accumulative relief formed on them are defined.

3. Aerial photographs are used in studying the dynamics of the principal exogenous and endogenous processes under present-day landscape-geographical conditions. Present-day valley and continental glaciers and snowfields, the presence of permafrost areas and processes of thawing and surface deformation associated with them, the nature of processes such as waterlogging, swamp formation and erosion, the horizontal pattern and density of the erosional network, karst, suffosion (undermining) and eolian processes are interpreted. Locally eluvial accumulations, rock streams, sheet erosion processes, and gravitational and slide processes of slope development are detected. Sectors of erosion and accumulation on the shores of seas, lakes, and reservoirs are noted. Areas where the relief has been acted upon by man's productive activity are clearly defined.

4. In studying the aerial photographs it is also possible to obtain information on the stages in development and relative age of relief. It is possible to distinguish relict, conservative, and newly forming embryonal elements in the present-day geomorphological landscape: ancient barrier beaches and abrasion benches, ancient dry valleys, overgrown dunes, marginal formations of ancient

glaciations which had different centers, sectors with manifestation of modern day intensive erosional degradation, karst phenomena, deflation, talus formation, landslides, mountain creep, etc. Locally it will be possible to determine the stages in manifestation of relief-forming processes: cycles of horizontal river channel migration accompanying lateral erosion of the banks, superposition of recent landslides on more ancient ones, reworking of the surfaces of accumulative sandy marine, lacustrine and river terraces of different age, etc.

5. Data from the preliminary interpretation are used in drawing up a plan for the field stage of geomorphological work: the direction and length of the field traverses is determined and the most convenient form of transportation, camping sites, "control" areas for studying the surface, geomorphological profiles and observation points, and sectors for describing geological cross sections are selected. /36

The field period of work begins with reconnaissance excursions for general familiarization with the terrain and geological-geomorphological conditions and revising the work program. The use of aerial methods makes possible a considerable reduction in reconnaissance work, particularly in thinly populated and inaccessible regions (high mountains, thickly forested or swampy areas). The field work is done along traverses selected in advance during the preliminary interpretation and in "control" sectors which are characterized by the most typical relief forms, the optimum openness, and distinct relationships between geological and geographic relief-forming factors. The detail of this work is dependent on the complexity of the geological-geomorphological structure, scale and purpose of the investigations. Geomorphological profiles can be described in uniform sectors.

Field interpretation is performed by field comparison of geomorphological features with their photo image on the aerial photographs; this makes it possible to refine data from the preliminary office interpretation and determine the characteristics of features which had not been studied due to their smallness or the lack of distinct interpretation criteria.

The control sectors are usually covered by a continuous geological-geomorphological survey. In addition, fauna is collected and samples are taken for analyses and other work is performed. On the basis of the defined interpretation criterial all the air photos are interpreted in the field and the results are plotted on a photomap or map. The air photos for the control sector, where a detailed study was made of the factors governing genesis of relief forms and the geological cross section, can serve as interpretation standards or keys. The areas between control sectors are interpreted using the minimum number of traverses and field observations.

The final office period of work with the use of aerial survey materials, in addition to the ordinary processing of ground observations, includes the processing of interpretation data.

A new examination of the aerial photographs, analysis of a large area at one time, allowance for all the collected geomorphological, geologic and tectonic data for the region, make possible a correct determination of the general patterns of geomorphological terrain structure, the dependence of the development of relief on tectonic structures, and sectors of manifestation of the most intensive recent or present-day movements, and the introduction of corrections to the results of the field interpretation. In the office it is possible to use more complete aerial materials and photogrammetric stereoapparatus for measuring the degree of slope and the dip of rock strata, peneplanes, relative elevation of terraces, etc.

Maps and profiles are compiled by transferring to photomaps various outlines and lines which were rectified during the final interpretation of the field working photos. The boundaries are transferred from the photomap onto tracing paper or Whatman's paper, on which the map compilations are prepared. In this procedure all the most interesting parts of the map can be illustrated by their photo images at different scales.

APPENDIX 1.

PRACTICAL COURSE ASSIGNMENTS

Assignment No. 1.

1. Make a preliminary layout of a teaching set of aerial photographs. Determine the percentage of end and side lap. Determine the air photo scales from the f and H parameters.

2. Determine the working centers and initial directions of a pair of air photos. Construct the coordinate system for the pair of air photos.

3. Orient the initial direction of an air photo stereopair parallel to the eye base and with the naked eye obtain a direct stereoeffect. Obtain a reverse stereoeffect.

4. Obtain a direct stereoeffect by an optical method, under a 3LS-1 stereoscope.

5. Determine the relative elevations of the points a and b in the coordinate system of the air photo pair by measuring the linear stereoscopic parallaxes.

Assignment No. 2.

1. Make a preliminary layout of a lab set of aerial photographs.

2. Successively examine the air photo stereopairs visually and under the stereoscope.

3. Employ direct interpretation criteria in writing a brief description of the surveyed sector, covering the following points:

a) surface structure (distribution of the principal orographic elements);

b) hydrographic elements (rivers, lakes, swamps, etc.; their size and relationship to relief);

c) vegetation (forest, meadow, etc.);

d) elements of the culture landscape (villages, cultivated lands, cutover areas, roads, bridges, etc.).

4. Compile a schematic topographic plan for the surveyed sector. In the legend give symbols for relief elements, hydrography, vegetation cover, and culture landscape.

Assignment No. 3.

1. Write up a description of a sector shown on the stereopair of air photos No. ..., covering the following points:

a) region, scale;

b) surface structure (strike of the principal orographic elements, their size, elevation, structure, microrelief);

c) hydrographic elements (rivers, lakes, swamps); /38

d) vegetation cover elements (forest, meadows, etc.);

e) development of the principal types of Quaternary deposits and their relationship to the relief;

f) hypothetical lithological composition of the Quaternary deposits;

g) hypothetical possibility of using the Quaternary deposits as minerals or otherwise (construction materials, fuels, salts, fill).

2. Compile a schematic map of Quaternary deposits (in the legend give the genetic types of deposits, hypothetical lithological composition, relative age).

Assignment No. 4.

1. Write up a description of the sector shown on the air photo stereopair No. ..., covering the following:

a) region, scale;

b) surface structure (strike of principal orographic elements, their size, structure, microrelief);

c) hydrographic elements (rivers, lakes, swamps);

d) vegetation cover elements (forest, meadows, steppe, etc.);

e) geological structure:
hypothetical lithological composition of the pre-Quaternary rocks;
tectontic elements (bedding of suites, disjunctive dislocations, fissuring);
distribution of genetic types of surface Quaternary deposits;
hypothetical prospects for finding minerals;

f) basic interrelationships in the distribution of relief elements and lithological varieties of rocks;

g) basic interrelationships in the distribution of relief elements and bedding conditions for the component rocks.

2. Compile a schematic geological map for the surveyed area.

Assignment No. 5.

1. Write up a description for the sector shown on the air photo stereopair No. ... according to the following items:

a) scale, region;

b) surface structure (strike of the principal orographic elements, their size, structure, microrelief);

c) hydrographic elements (rivers, lakes, swamps);

d) vegetation cover elements;

e) geological structure:

sectors in which igneous rocks occur, their relationship to relief elements;

hypothetical petrographic composition of the component rocks;

tectonic elements;

distribution of principal genetic types of Quaternary deposits and their hypothetical lithological composition;

hypothetical prospects for finding minerals.

2. Compile a schematic geological map of the surveyed area.

Assignment No. 6.

1. Write up a geomorphological description of the sectors shown on the lab set of aerial photographs No. ..., covering the following points:

a) scale, region;

b) basic morphogenetic relief types, their distribution, natural boundaries, interrelationships;

c) morphometric data on the most important relief elements and combina- /39 tions of elements for the discriminated types (strikes, sizes, relative elevations). Interrelationships of macro-, meso-, and microforms;

d) characteristics of elements of the defined forms (structure of peaks, slopes, valleys, in plan and in longitudinal and transverse cross sections);

e) relationship between relief types and forms and the geological structure, lithological varieties of the component rocks, their bedding conditions, faults, fracturing, sectors with different genetic types of Quaternary deposits;

f) description of geographic relief-forming factors:
erosion and waterlogging conditions;
presence of permafrost, swampy areas, sectors with manifestation of present day erosion, abrasion, slope creep, gravitational processes, karst formation, terrace reworking, etc.

2. Compile a schematic geomorphological map of the sector. In the legend discriminate the basic morphogenetic relief types and the most important forms; indicate their hypothetical geological age; show the proposed field traverses, profiles and exposures, as well as camp sites.

APPENDIX 2.

CURRICULUM FOR A COURSE ON THE GEOMORPHOLOGICAL INTERPRETATION OF AERIAL PHOTOGRAPHS

1. Aerial methods in geological-geomorphological studies; the theoretical and practical importance of their use.

2. Aerovisual observations (basic content of method, its merits and shortcomings, importance).

3. Method of aerovisual observations (planes, time, altitudes, flight directions under different geographical conditions).

4. Use of the aerovisual method in geological-geomorphological surveys.

5. Use of the aerovisual method in mineral exploration.

6. Use of aerovisual observations in geological engineering field work.

7. The principal air photo survey materials used in geological-geomorphological work.

8. Interpretation of aerial photographs and the field of its applicability.

9. Direct and indirect interpretation criteria.

10. Dimensions of natural features and their determination on air photos.

11. Shape of natural features on air photos.

12. Spatial position of natural features on air photos.

13. Shadows as an interpretation criterion.

14. Tonal interpretation criteria.

15. Air photo image patterns on air photos.

16. Geobotanical interpretation criteria.

17. Types of interpretation. Instruments used in interpretation work.

18. Stereoscopic properties of air photos and their use in geological-geomorphological investigations.

19. Methods for determining relative elevations from air photo stereopairs.

20. Principal criteria for interpreting Quaternary deposits. /40

21. Interpretation of glacial deposits and forms of accumulative-glacial relief from air photos.

22. Interpretation of kame deposits and forms of accumulative kame relief.

23. Interpretation of fluvioglacial deposits, eskers, outwash plains.

24. Interpretation of alluvial fans (proluvium) and associated relief forms.

25. Interpretation of alluvial deposits and erosional-accumulative relief forms of fluvial origin.

26. Interpretation of slopes.

27. Interpretation of eluvial deposits and their importance.

28. Interpretation of landslides, talus and rockfalls.

29. Interpretation of deluvial processes (creep, slides, etc.).

30. Interpretation of swamps and peat bog deposits.

31. Interpretation of regions with permafrost and associated relief forms.

32. Interpretation of denudation-structural relief.

33. Interpretation of denudation-tectonic relief.

34. Interpretation of sedimentary rocks on the basis of lithomorphogenic criteria.

35. Determination of types of rock bedding from aerial photographs.

36. Determination of disjunctive dislocations from air photos.

37. Interpretation of igneous rocks.

38. Interpretation of relief forms of volcanic origin.

39. Method for organizing geological-geomorphological work using air photos.

40. Content of schematic geomorphological map compiled using data from a preliminary interpretation of air photos.

APPENDIX 3.

Schematic geomorphological map of sector No. 18 (compiled using materials from the interpretation of air photos).

Symbols:

I. Morphogenetic relief types and forms.

A. Denudation-structural remnant relief on Lower Cretaceous sandstones; age Ng - Q_{II}:

a) flat-topped remnants,

b) steep slopes with scarps formed by denudation,

c) v-shaped deep gullies.

B. Accumulative relief of deluvial slopes on permafrost; age Q_{III} - Q_{IV}:

a) gentle slopes with dells.

C. Erosional-accumulative relief of river valleys; age Q_{III-IV}:

a) river terrace complex,

b) dry channel,

c) brows of river terraces,

d) brows of erosional scarps,

e) ox-bow lakes,

f) alluvial fan.

D. Denudation thermokarst relief; age Q_{III-IV}:

a) undrained lake basins.

II. Rose diagram of directions of lineaments measured from air photos.

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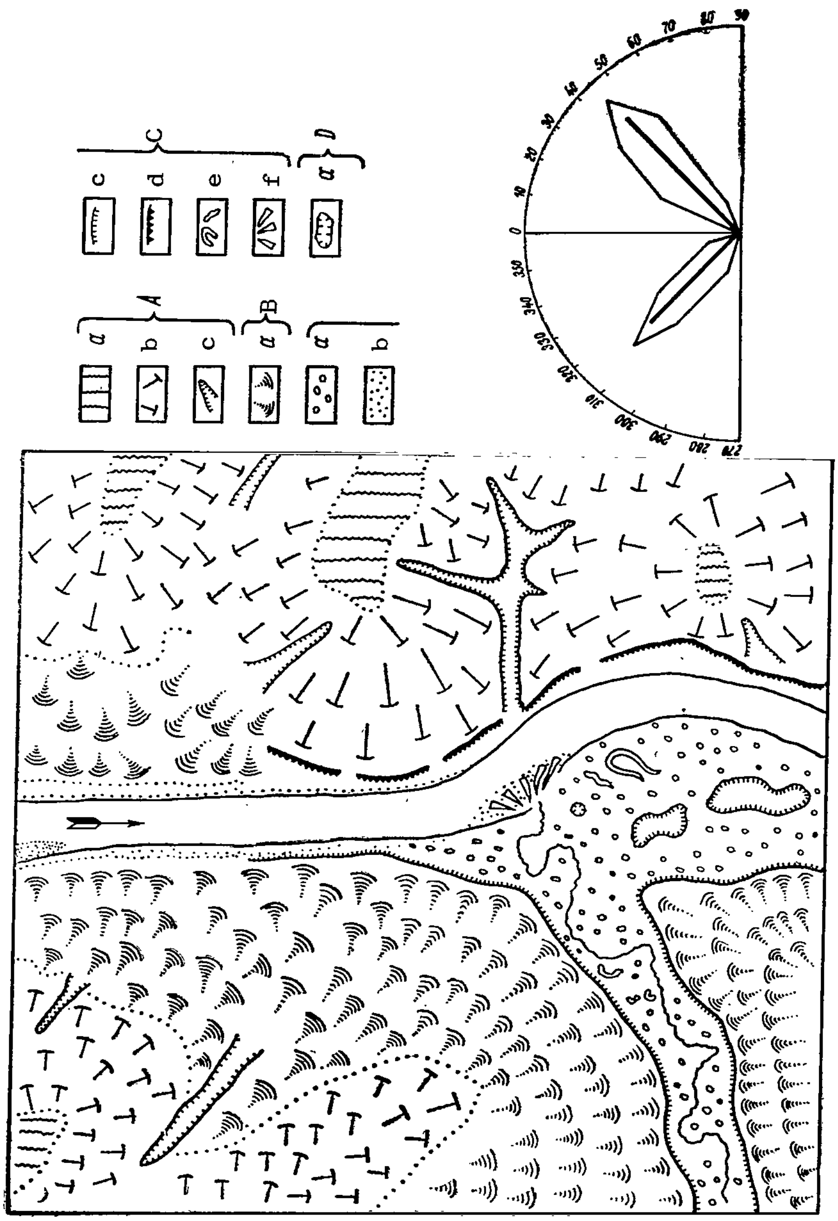
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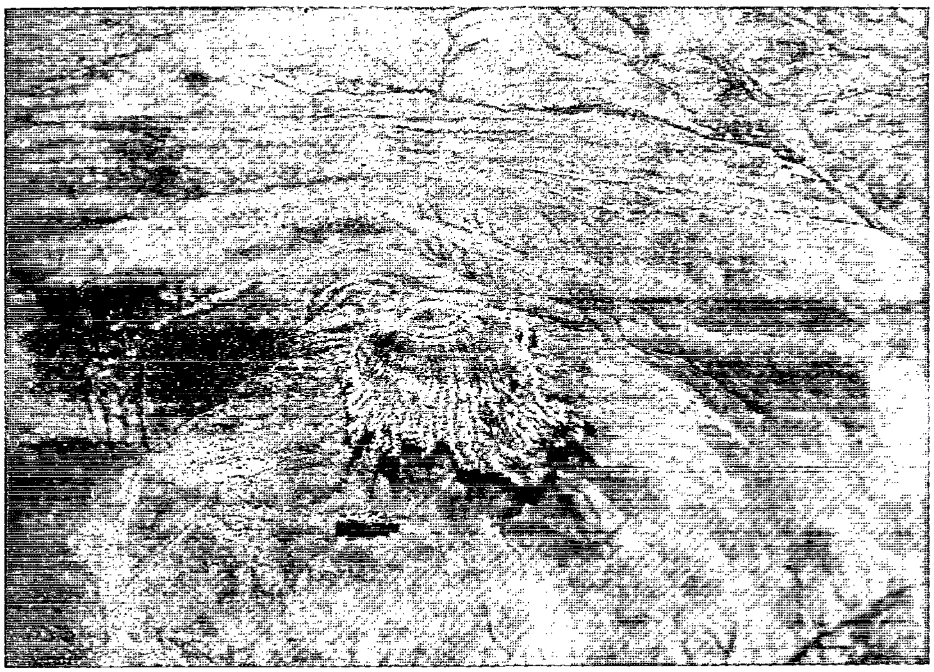

Figure 1. Denudation remnant with steep slopes dissected by erosion. Aerovisual observations. Oblique aerial photograph (from V. P. Miroshnichenko).

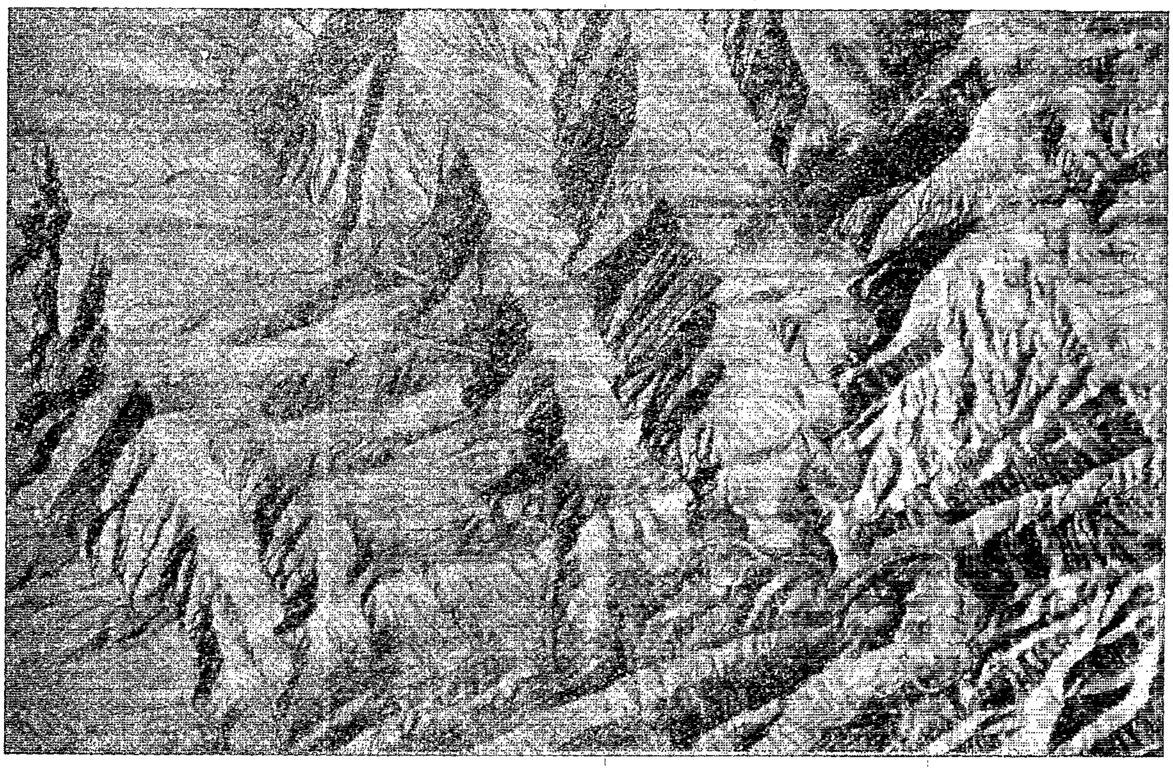

Figure 2. Erosionally denuded relief in mountains of intermediate elevation on monoclinally bedded, steeply dipping Cretaceous strata. The stratum dip is determined from the nature of the stratum triangles. Large-scale aerial photograph.

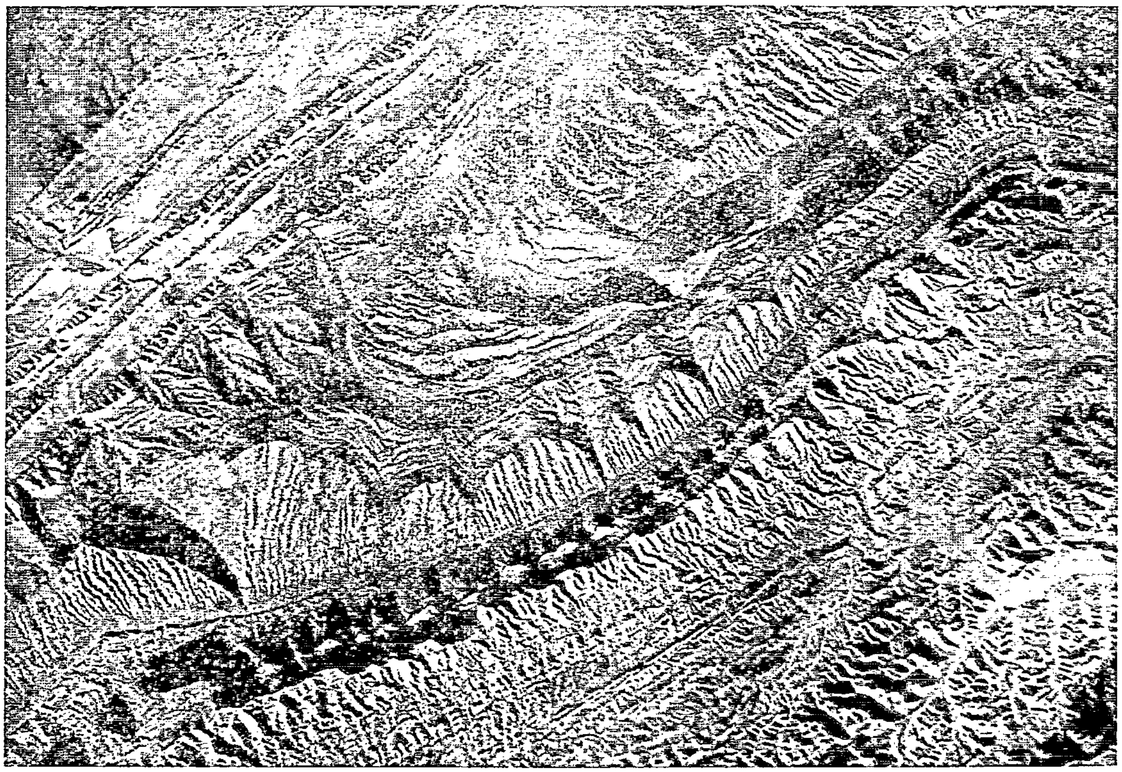

Figure 3. Pericline of anticlinal fold in Cretaceous deposits. Photomap.

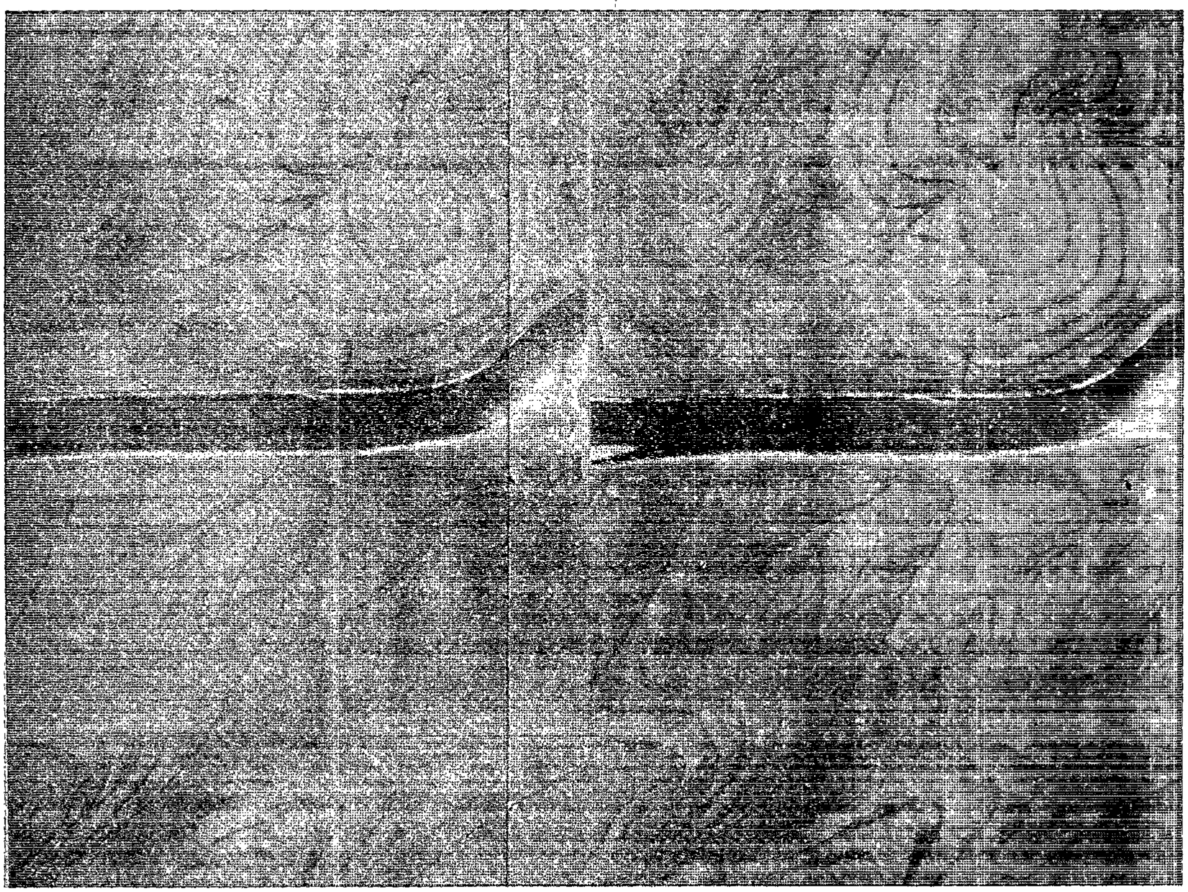

Figure 4. Denuded structural relief of flat-topped remnants with steep stepped slopes on horizontally bedded, poorly erodable rocks; on the lower part of the interfluve slopes, talus deposits (striated photo image pattern). In river valley, erosional scarps, terraces, thermokarst basins, sand bars. Stereogram of small-scale air photos.

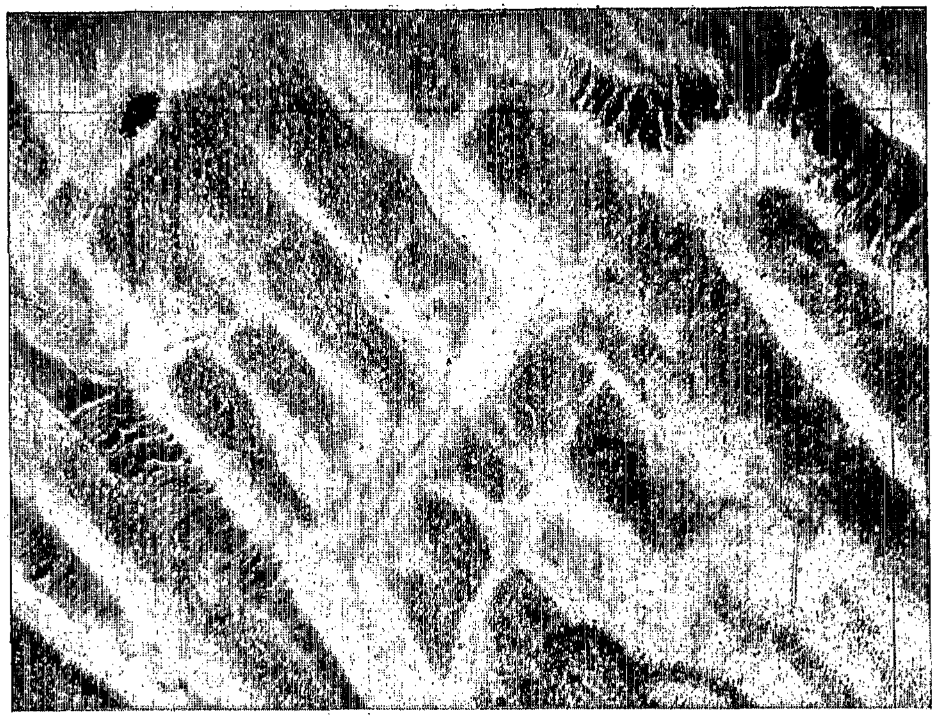

Figure 5. Accumulative glacial ridged-hilly relief. In the depressions between the ridges there are swampy areas with ridged-swampy meadow microrelief. Large-scale air photo.

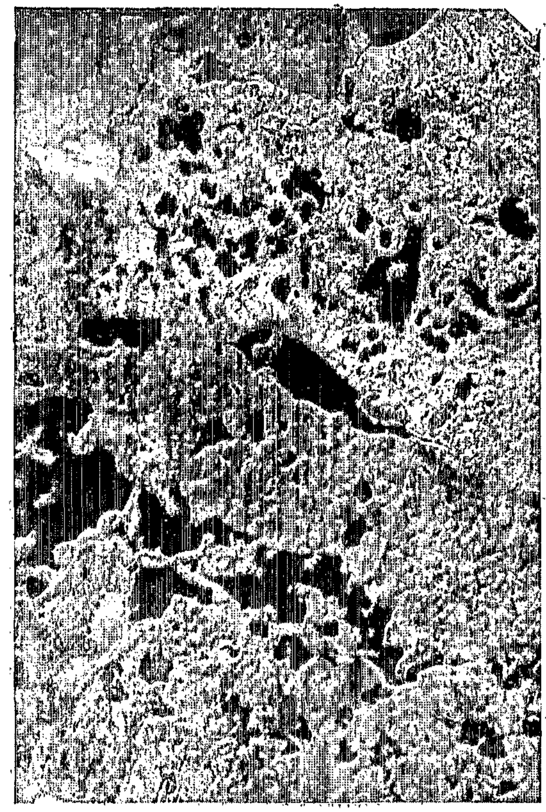

Figure 6. Terminal moraine relief of Upper Pleistocene glaciation. Small-scale air photo.

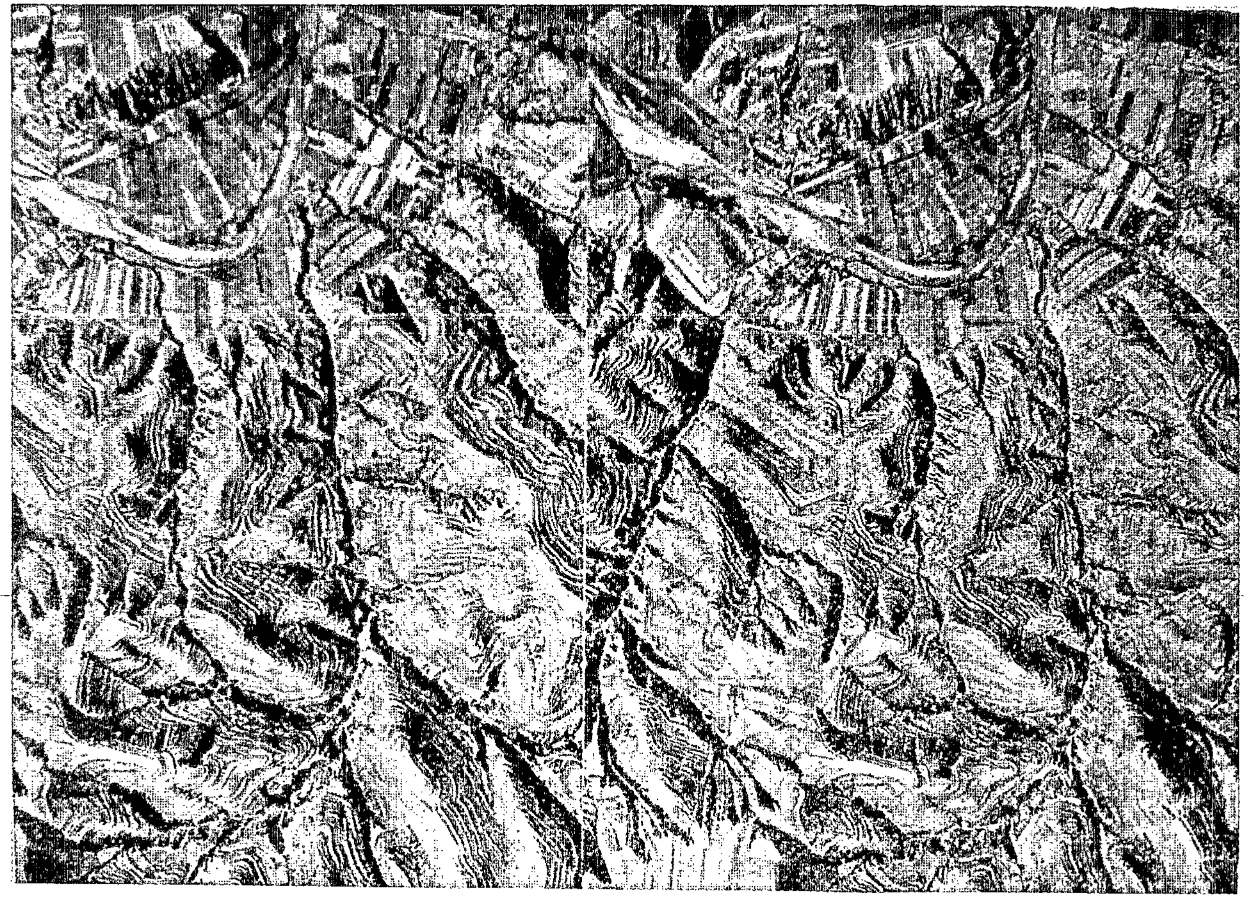

Figure 7. Accumulative relief on loessial plateaus dissected by deep branching gullies. Stereogram of air photos at intermediate scale.

Figure 8. Denuded scarp with talus fan at foot. Oblique aerial photograph (from V. P. Miroshnichenko).

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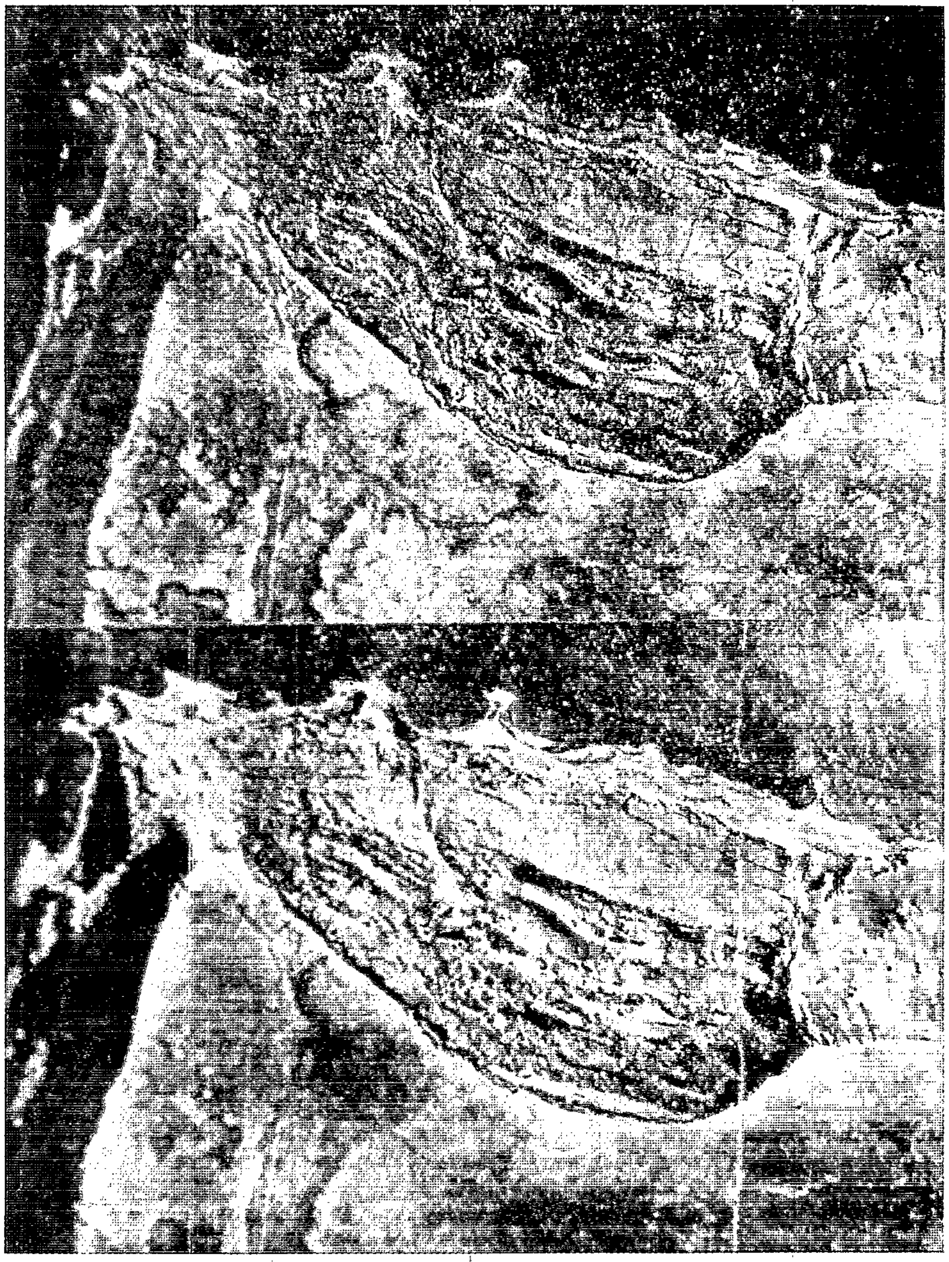

Figure 9. Structurally denuded plateau on horizontally bedded Sarmantian limestones with remnants of salt lakes and undrained depressions. The plateau descends to the sea in steep chink scarps complicated by landslides. Stereogram of large-scale air photos.

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Figure 10. Lake in karst depression in dislocated Permian limestones. Large-scale aerial photograph.

Figure 11. Landslide slope in psammitic-marly fissured Cretaceous deposits. Intermediate-scale air photo.

Figure 12. Denuded relief of ridges and low hills on extrusive-sedimentary dislocated Silurian rocks. Large-scale air photo (from V. P. Miroshnichenko).

Figure 13. Ancient erosional valley among ridged-honeycomb sands in desert. Oblique aerial photograph.

Figure 14. Eolian relief of polysynthetic barchans on surface of Early Khvalynskiy marine terrace bounded by ancient abrasional bench. Stereogram of large-scale air photos (continued on page 69).

Figure 14 (concluded).

Figure 15. Marine abrasional-accumulative terraces. Fine-ridged eolian microrelief on the upper terrace. Underwater relief complicated by fault systems. Large-scale air photo.

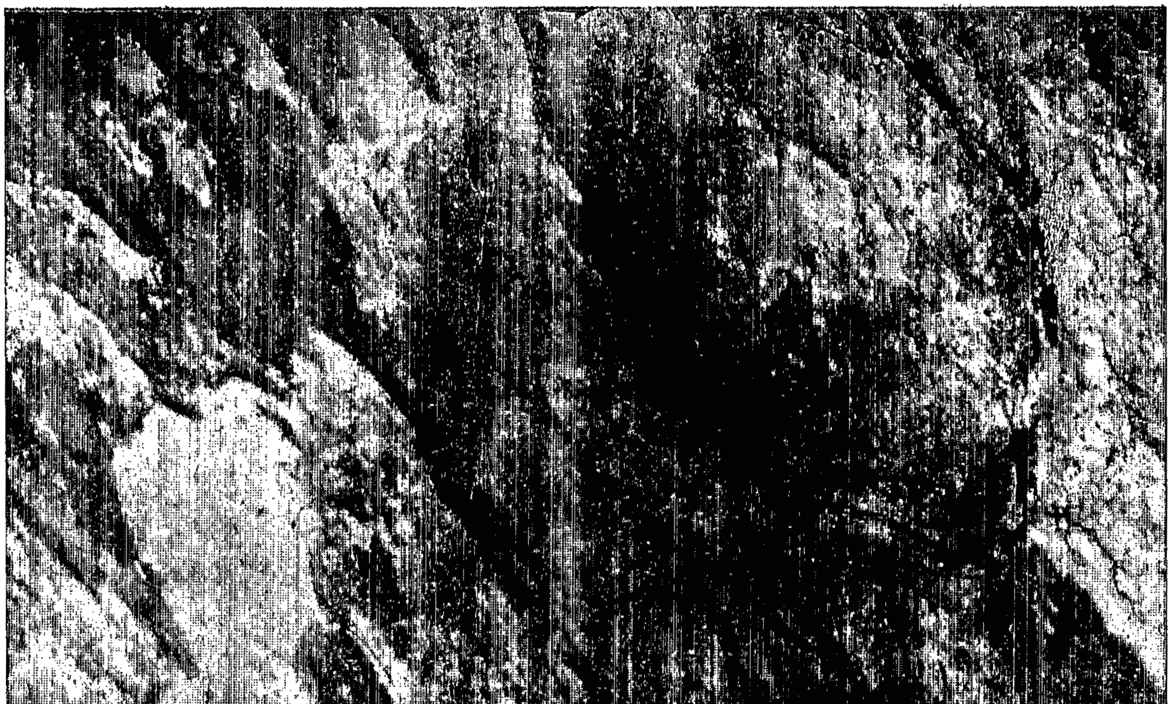

Figure 16. Eolian accumulative ridged relief intersected by ancient ravine valley with terraces. Large-scale air photo.

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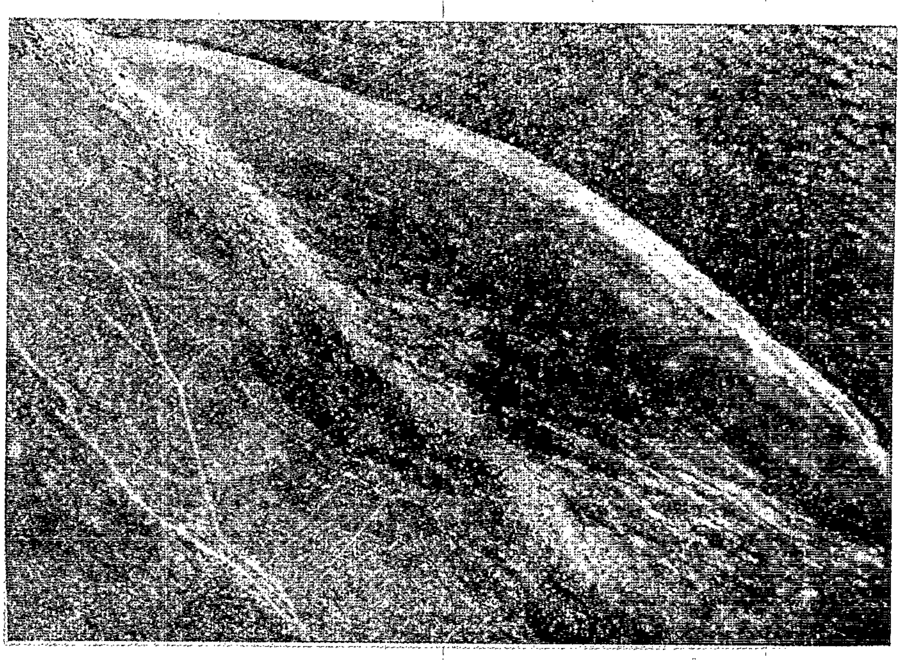

Figure 17. Ancient Caspian Quaternary terraces. Waste accumulations are observed at the foot of the abrasion benches. Large-scale air photo (from V. V. Sharkov).

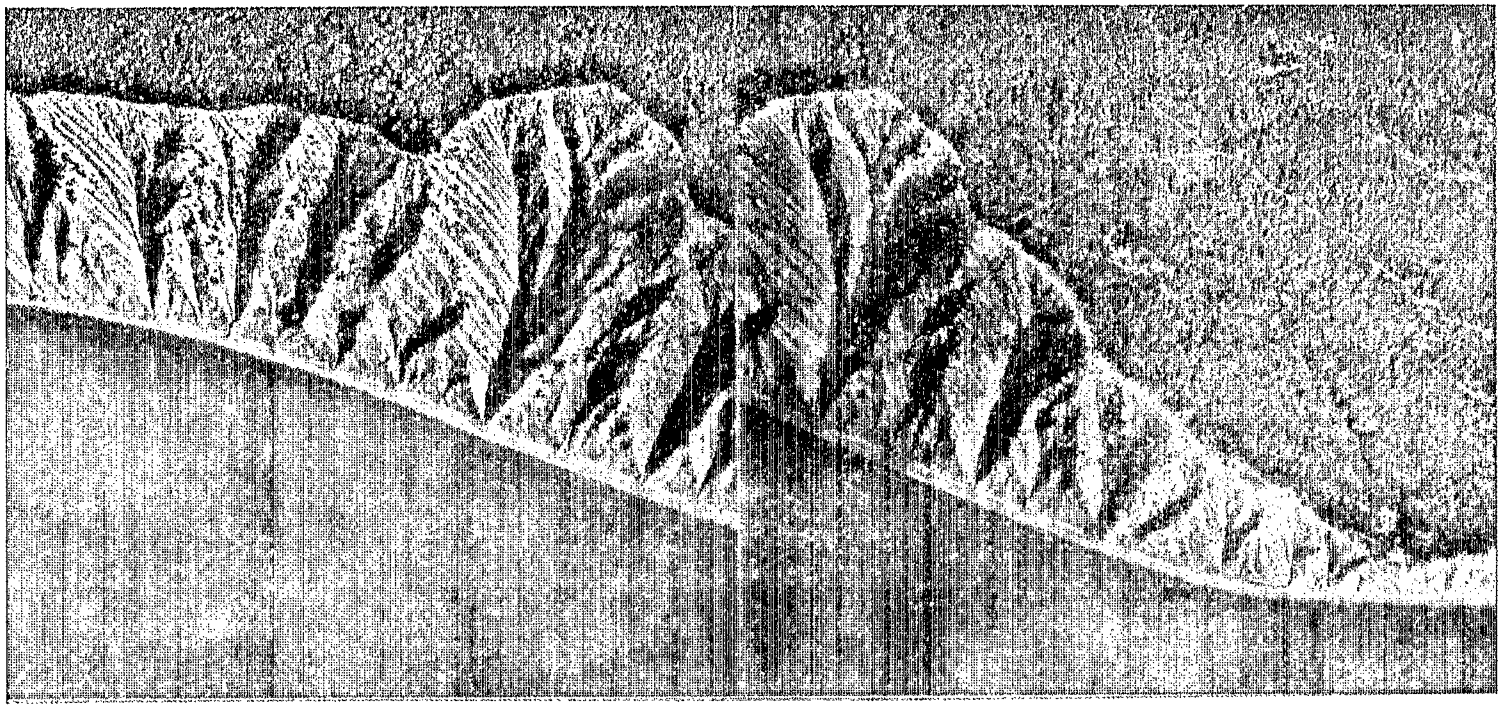

Figure 18. Steep abrasion scarp dissected by gullies. Stereopair of large-scale air photos.

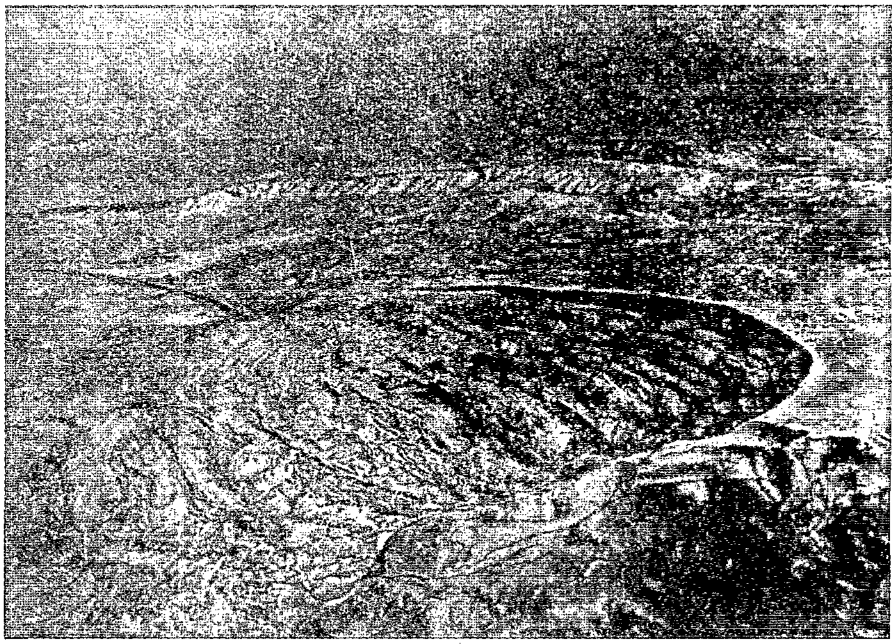

Figure 19. Ancient cirquelike slide. Oblique air photo.

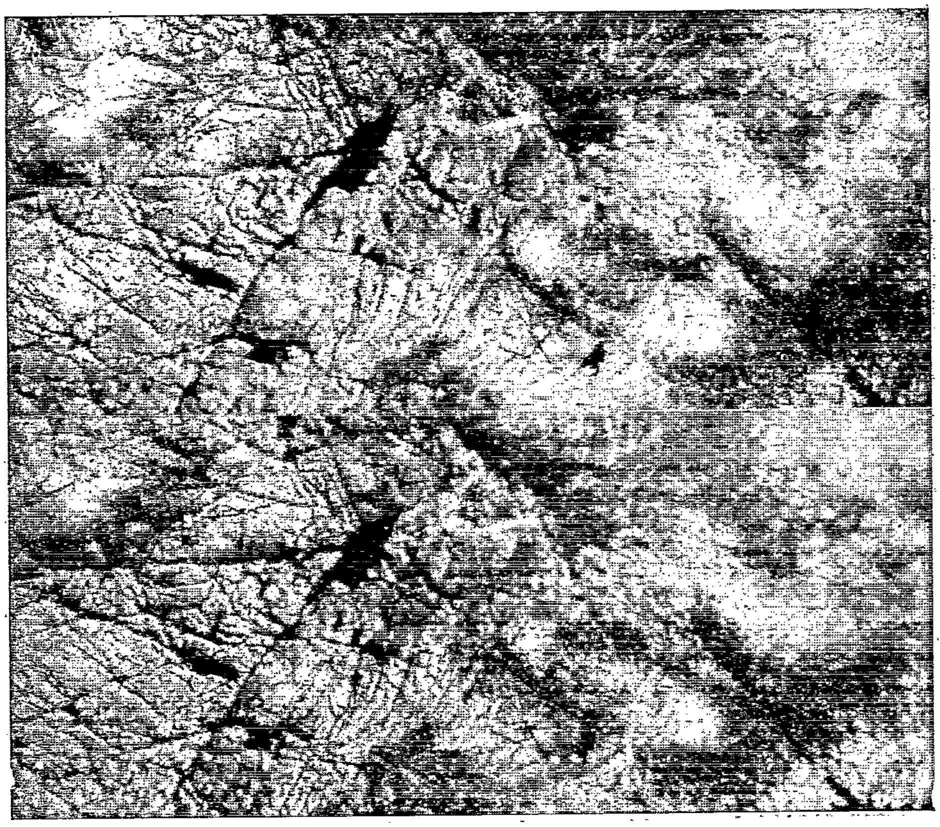

Figure 20. Denuded plain on granite batholith. Lake and valley inlets extend along the systems of fissures intersecting at an acute angle. Stereogram of small-scale air photos.

Figure 21. Denuded tectonic relief of high hills on intrusive rocks with porphyrite and diabase dikes. Large-scale air photo (from V. P. Miroshnichenko).

Figure 22. Table-topped highland associated with trap sill (C). Large-scale air photo.

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